IDRC-151e

CASSAVA CULTURAL PRACTICES

Proceedings of a workshop held in Salvador, Bahía, Brazil, 18-21 March 1980

Editors:
Edward J. Weber, Julio Cesar Toro M., and Michael Graham

Organized by:
Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)
Centro Internacional de Agricultura Tropical (CIAT)
International Development Research Centre (IDRC)

The International Development Research Centre is a public corporation created by the Parliament of Canada in 1970 to support research designed to adapt science and technology to the needs of developing countries. The Centre's activity is concentrated in five sectors: agriculture, food and nutrition sciences; health sciences; information sciences; social sciences; and communications. IDRC is financed solely by the Parliament of Canada; its policies, however, are set by an international Board of Governors. The Centre's headquarters are in Ottawa, Canada. Regional offices are located in Africa, Asia, Latin America, and the Middle East.

Postal Address: Box 8500, Ottawa, Canada K1G 3H9
Head Office: 60 Queen Street, Ottawa, Canada

Weber, E.J.
Toro M., J.C.
Graham, M.

Empresa Brasileira de Pesquisa Agropecuária, Brasilia BR
Centro Internacional de Agricultura Tropical, Cali CO
IDRC Ottawa CA

IDRC-151e

Cassava cultural practices : proceedings of a workshop held in Salvador, Bahía, Brazil, 18–21 March 1980. Ottawa, Ont., IDRC, 1980. 152 p. : ill.

/IDRC publication/, /cassava/, /cultivation practices/ — /planting/, /plant production/, /crop yield/, /storage/, /soil fertility/, /fertilization/, /soil management/, /weed control/, /agricultural mechanization/, /agricultural research/, /recommendation/, /agricultural statistics, list of participants.

UDC: 635.23:631.58 ISBN: 0-88936-245-9

Microfiche edition available

IDRC-151e

Cassava Cultural Practices

Proceedings of a workshop held in Salvador, Bahía, Brazil, 18–21 March 1980

Editors: Edward J. Weber, Julio Cesar Toro M., and Michael Graham

Organized by:
Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)
Centro Internacional de Agricultura Tropical (CIAT)
International Development Research Centre (IDRC)

Contents

Foreword 5
Participants 7
Discussion Summary and Recommendations 9

Agronomic practices for cassava production: a literature review
Julio Cesar Toro M. and Charles B. Atlee 13

Cassava planting material: management practices for production
Abelardo Castro M. 29

Influence of period and conditions of storage on growth and yield of cassava
Antonio M. Sales Andrade and Dietrich E. Leihner 33

Cassava production and planting systems in Brazil
José Osmar Lorenzi, Edgard Sant'Anna Normanha, and Antonio José de Conceição 38

Cassava planting systems in Africa
H.C. Ezumah and B.N. Okigbo 44

Cassava planting systems in Asia
Sophon Sinthuprama 50

Double row planting systems for cassava in Brazil
Pedro Luis Pires de Mattos, Luciano da Silva Souza, and Ranulfo Correa Caldas 54

Soil-related cultural practices for cassava
Reinhardt H. Howeler 59

Soil and water conservation and management for cassava production in Africa
H.C. Ezumah, R. Lal, and B.N. Okigbo 70

Soil-related intercropping practices in cassava production
Carlos F. Burgos 75

Long-term fertility considerations in cassava production
S.K. Chan 82

Cassava production in low fertility soils
Jaime de Cerqueira Gomes and Reinhardt H. Howeler 93

Chemical weed control in cassava
José Eduardo Borges de Carvalho 103

Cultural control of weeds in cassava
Dietrich E. Leihner 107

Integrated control of diseases and pests of cassava
J.C. Lozano and A.C. Bellotti 112

Mechanical planting and other cassava cultural practices in Cuba
Adolfo Rodríguez Nodals 118

Cultural practices for large cassava plantations
Hélio Correa 120

The effect of mycorrhizal inoculation on the phosphorus nutrition of cassava
Reinhardt H. Howeler 131

Bibliography 138

Foreword

A wide range of research has been done on cultural practices related to cassava production in the various ecosystems of the world where cassava is currently produced. This information is not available in a single document nor have the results been evaluated or interpreted in a manner that is useful to national cassava research and extension programs. This publication covers the proceedings of a four-day meeting that took place in Salvador, Bahía, Brazil, and brings together most of the existing information on cultural practices and presents general recommendations for increasing cassava productivity and for further research efforts. It represents the 17th volume in the IDRC Cassava Series and is the 13th that reports on the findings of a workshop. These meetings have been organized in collaboration with various research institutions working on cassava and particularly with the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia. Usually, a small number of experienced researchers and policymakers from around the world are invited to present papers on specific topics or problems and to discuss these papers in a structured way as a basis for recommending further research and program priorities. Despite the large amount of cassava produced in Brazil (31% of the world total), this was the first of the cassava workshops to enjoy substantial participation and technical contribution from Brazilian researchers. Indeed, it was to achieve this participation that the meeting was organized in Brazil at the invitation of Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA).

In any cassava production improvement program, the introduction of better cultural practices is usually the first step that can be taken to rapidly increase yields and productivity. It has been suggested that some research results are likely to be universal in their application, relatively independent of their environment or scale of application. Other research results and technological recommendations are more affected by agroclimatic conditions and need verification on a site-specific basis. A good example of the former is the selection, treatment, and handling of cassava planting material, and of the latter, soil and water management technology. Other results require additional research and fine-tuning to bring them to the level of practical recommendations for producers. The workshop attempted to review these research results in relation both to commonly used production practices and producer resource endowments and to special situations, such as the large plantation management techniques required for production of cassava to supply Brazil's massive fuel alcohol production program.

On the first day of the meeting the group visited the Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF) at Cruz das Almas, Bahía, and a small cassava-flour processing facility. The formal meetings were initiated by an opening address by Dr Raymundo Fonseca Souza, Director of EMBRAPA, of which CNPMF is a part. Eighteen papers were presented in six separate sessions organized under the following headings: (1) production and storage of cassava planting materials; (2) cassava planting systems and practices; (3) soil-related cultural practices including (a) soil conservation and management practices and (b) soil fertility considerations; (4) phytosanitary and weed control practices; (5) mechanization and cultural practices for large plantations, and (6) mycorrhiza and the uptake of phosphorus by cassava.

Special recognition and thanks are extended to the Secretary of Agriculture of Bahía, Dr Renan Rodrigues Baleeiro, who sponsored an opening reception and warmly welcomed the participants to Bahía, one of the principal cassava producing states of Brazil. Many thanks are due to Dr Raymundo Fonseca Souza and his staff for their strong interest as well as organizational support. The participants also enjoyed the hospitality of Brascan Nordeste whose director, Dr Diogenes Cabral do Vale, generously sponsored a dinner at the Bahía Yacht Club. This company has been supporting cassava research in Brazil since 1973. Mention must be made of the valuable contribution of the five rapporteurs, W. Godfrey-Sam-Aggrey, Marianito Villanueva, Abelardo Castro. Fernando Ezeta, and Mario Augusto Pinto da Cunha, who commented on the methodological papers and summarized the content of ensuing discussions. The discussion summary and recommendations section of this publication is based on their reports.

It is our sincere hope that the information and recommendations compiled in this publication will prove useful and stimulating to cassava researchers, extension program managers and planners, cassava growers, and agricultural development policymakers. We hope that it will serve to inspire new advances in research and improved cassava production management.

Edward J. Weber
Senior Program Officer — Crops and Cropping Systems
Agriculture, Food and Nutrition Sciences Division
International Development Research Centre
and
Julio Cesar Toro M.
Agronomist, Cassava Program
Centro Internacional de Agricultura Tropical

Participants

Antonio Monteiro Sales de Andrade, Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), Av. Amazonas 115, Sala 619, 30.000 Belo Horizonte, Minas Gerais, Brazil.

Anthony Bellotti, Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia.

José Marcelo Garcia Bessa, Empresa de Pesquisa Agropecuária de Pernambuco (IPA), Av. San Martin, 1371 Bongi, Recife, Pernambuco, Brazil.

Carlos Burgos, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica.

José Eduardo Borges de Carvalho, Escola Superior de Agricultura Luiz de Queiroz, Programa de Posgraduacion, Caixa Postal 9, 13.400 Piracicaba, São Paulo, Brazil.

Paulo César Lemos de Carvalho, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Yolanda de Castellanos, Agriculture, Food and Nutrition Sciences Division, Centro Internacional de Investigaciones para el Desarrollo (CIID), Apartado Aéreo 53016, Bogotá, Colombia.

Abelardo Castro, Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia.

Chan Seak Khen, Malaysian Agricultural Research and Development Institute (MARDI), Beg Berkunci No. 202, Pejabat Pos Universiti Pertanian Malaysia, Serdang, Selangor, Malaysia.

Antonio José da Conceição, Jefe Departamento de Fitotecnia, Universidade Federal da Bahía, Cruz das Almas, Bahía, Brazil.

Helio Correa, Escola Superior de Agricultura de Lavras, 37.200 Lavras, Minas Gerais, Brazil.

Mario Augusto Pinto da Cunha, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Jorge Luiz Loyola Dantas, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Fernando Ezeta, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

H.C. Ezumah, International Institute of Tropical Agriculture (IITA), PMB 5320, Ibadan, Nigeria.

Alba Rejane Nunes Fairas, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Raymundo Carlos Nery Filho, Secretaria da Indústria e Comércio, Centro Administrativo da Bahía, Brazil.

Márcio José Furtado, Empresa Capixaba de Pesquisa Agropecuária (EMCAPA), Caixa Postal 391 — Vitoria, ES, Brazil.

W. Godfrey-Sam-Aggrey, University College of Swaziland, P.O. Luyengo, Swaziland, Southern Africa.

Jayme de Cerqueira Gomes, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Michael Graham, Communications Division, International Development Research

Centre (IDRC), P.O. Box 8500, Ottawa, Canada K1G 3H9.

George R. Homer, SBDAL, Ed. Maristela, s/314, Brasilia, DF, Brazil.

Reinhardt H. Howeler, Cassava Program, Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia.

Dietrich Leihner, Cassava Program, Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia.

Raúl Carcelen Longo, Instituto Nacional de Investigaciones Agropecuarias (INIAP), Extación Experimental, Pichilingue, Apartado 24, Quevedo, Ecuador.

José Osmar Lorenzi, Instituto Agronomico de Campinas, Seção de Raízes e Tubéculos, Caixa Postal 28, 13.100 Campinas, Sao Paulo, Brazil.

Pedro Luiz Pires de Mattos, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Rui Américo Mendes, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Edgard Sant'Anna Normanha, Instituto Agronomico de Campinas, Seção de Raízes e Tubérculos, Caixa Postal 28, 13.100 Campinas, Sao Paulo, Brazil.

Sebastião de Oliveira e Silva, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

José Carlos Arruti Rey, Secretaria da Indústria e Comércio, Centro Administrativo da Bahía, Salvador, Bahía, Brazil.

Jairo Ribeiro da Silva, Empresa Brasileira de Transferencia de Tecnologia y Extensão Rural (EMBRATER), Av. W3 Norte — Quadra 515, Bloco C, 70.770 Brasilia, DF, Brazil.

Sophon Sinthuprama, Field Crops Division, Department of Agriculture, Bangkhen, Bangkok 9 Thailand.

Gernack Ferraz Souto, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

José da Silva Souza, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Luciano da Silva Souza, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF/EMBRAPA), Caixa Postal 007, 44.380 Cruz das Almas, Bahía, Brazil.

Milton Moreira de Souza, Superintendencia do Desenvolvimento do Nordeste (SUDENE), Cidade Universitária, Recife, Pernambuco, Brazil.

Raymundo Fonseca Souza, Director, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Caixa Postal 1316, 70.00 Brasilia, DF, Brazil.

Armando Takatsu, Departamento de Biologia Vegetal, Universidade de Brasilia, 70.910 Brasilia, DF, Brazil.

Julio Cesar Toro M., Cassava Program, Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia.

Marianito Villanueva, Philippine Root Crop Research and Training Center, 8 Lourdes Street, Pasay City, Philippines.

Edward J. Weber, Agriculture, Food and Nutrition Sciences Division, Centro Internacional de Investigaciones para el Desarrollo (CIID), Apartado Aéreo 53016, Bogotá, Colombia.

Discussion Summary and Recommendations

(1) The production and availability of good cassava propagation material are important factors for successful cassava production and improved yield. Great stress was placed on the importance of utilizing healthy planting material that is properly treated and handled. The range of methods available for producing, selecting, and handling this material was discussed with attention being drawn to the economics of these activities and the different requirements of small and large producers. Extension programs dealing with cassava, especially those aimed at small producers, could increase cassava productivity considerably by encouraging and organizing the use of recommendations set out in the relevant workshop papers included in this publication.

(2) The establishment of cassava multiplication plots for the production of certified propagation material was suggested as a way of producing viable, good quality, healthy planting material. This could be particularly important for cassava production on infertile soils where top growth may provide inadequate stake material. The nursery in most cases would be located on the best soils available close to the production area and receive special attention in terms of disease and pest control, roguing and burning of infected plants, good weed control, and possibly heavy fertilization to increase top growth. The possible disadvantages of this system are the cost and the high level of organization and management required.

(3) In most cases, planting material will still be taken from production areas, but special methods could improve the viability and quality of the stakes. One possible measure is the selection of the best part of the field or plantation for special attention and care to ensure good healthy plants and the harvesting of this area last or shortly before planting to avoid extended storage of the stakes. This measure is applicable principally to medium and large producers but small producers could also improve their cassava productivity by more careful selection of planting material within their small plots and by following better treatment and planting practices. The selection of planting material is often related to the total use made of the plant. Elimination or deterioration of available planting material can result when plants are harvested on a continuous basis for consumption or cash sale or if leaves are removed for human or animal food. In a dry or adverse season this effect can be more severe. It was suggested that larger producers or specialized plantations producing principally stakes might provide certified material for all growers in a region. Questions were raised about the economics of this possibility.

(4) Rapid propagation techniques have not been fully exploited or developed for production of planting material and it was suggested that this possibility should receive further research and development. Greenhouse production of planting material should also be explored.

(5) In some areas where there is a prolonged cold period, such as in southern Brazil, or a dry period between the normal time of harvesting and the time of planting, it is necessary to store planting material. If this material is not managed properly, the stand and yield of subsequent crops can be reduced considerably. Studies are under way on preservation techniques using hormones and on rehydration of stakes before planting but this work is only beginning. Research is required to develop improved storage methods for hot and dry, flooded, and winter environmental conditions and to relate length of storage time under each of these methods and conditions to sprouting, early plant growth vigour, and root yield. The parameters for optimum storage conditions require more precise definition as does the effect of the nutritional quality of the stake on storability. The possibility of prefertilization of stakes with nutrient solutions to improve sprouting and early growth vigour should be investigated as well.

(6) In areas with cold or dry periods, where pruning is required or die-back is experienced, it is possible to cut the stalks before die-back occurs and store them for planting at a later date. This method should be explored for stake production. Using a similar system, IITA was able to produce sufficient planting material for 20 ha on only 1 ha. The regeneration rate of the plant should be studied and the number of cycles that can be achieved without reducing stake quality and viability should be determined. CIAT achieved only two cycles of useful material using this pruning practice on a ridged heavy soil without fertilization or chemical applications and where root decomposition is normally experienced by the second year.

(7) It was generally agreed that there is no yield advantage in using stakes longer than 30 cm. However, if growing conditions are poor, the use of longer stakes may give an advantage in providing early plant vigour.

(8) There was no unanimous preference for planting position of stakes. In general, the vertical position recommended by CIAT is the least risky and will give the best results under most conditions. It must be recognized, however, that local conditions and farmer preferences can alter this recommendation and it was suggested that further evaluation be done under a range of agroclimatic conditions and farmer production systems to ascertain the best method to use in each particular locality. Some factors that affect choice of planting position are rainfall distribution, wind intensity, management practices, final utilization of the crop (e.g. where leaves are consumed it might be desirable to use a horizontal position which tends to produce more top growth), soil conditions, and methods used by farmers in performing other field operations. The advantages and disadvantages of each position should be clearly specified in terms of local conditions.

(9) Cassava is grown on hillsides in many parts of the world and, in the absence of adequate soil conservation practices, it can contribute to erosion. Research is needed to determine the performance of the crop under minimum tillage conditions and methods of land preparation that combat soil erosion without affecting cassava root yields. Unanimous concern was expressed regarding the need for adequate ground cover to avoid soil erosion and nutrient losses. The importance of soil preparation cannot be overstressed but studies of its long-term effects on soil structure, compaction, drainage, etc. are needed. This is particularly true when mechanized land preparation, weed control, and harvesting are to be used as in the Brazilian Cerrado where heavy machinery is

used for all crops. Improved tillage implements and hand tools for use under minimum tillage and slope conditions could be developed and it was suggested that at least one international or national research centre should initiate research in this area. Mechanical harvesting can possibly provide the seed bed for the following crop. This would help to achieve minimum tillage. A prototype harvester has been developed in Cuba that pulls rather than digs cassava plants, disturbing much less soil.

(10) It was generally concluded that traditional intercropping production systems utilized by small farmers are relatively efficient in controlling soil erosion and maintaining soil fertility and crop yields. Although it is commonly believed that cassava is a soil depleting crop, data presented at the meeting indicated that this is not the case and that cassava is no worse than many other crops in this respect. Most participants agreed that soil depletion effects attributed to cassava have often been exaggerated and are the result of poor management practices as well as of the position cassava occupies in crop sequences rather than of factors inherent in the crop itself.

(11) There was general consensus that crop rotation, intercropping systems, and the use of green covers and mulches are practices to be recommended to avoid soil erosion and nutrient losses, especially on steep slopes. Some of these practices are more difficult to apply in large-scale commercial cassava production; however, adaptations should be made and further research conducted on green covers and double-row planting systems. The latter technique could reduce the amount of tillage and fertilizer required, reduce the spread of pests and diseases, and combat erosion.

(12) With respect to fertilization of cassava, it seems that nutrient requirements in different types of soils are highly variable and researchers are unable to provide general fertilization recommendations. As a guideline, however, research in the Eastern plains of Colombia and in the Cerrado of Brazil indicates that cassava is very well adapted to acid soils hence lime is not required in large quantities to neutralize soil acidity. Low level applications ($\pm$0.5 t/ha) of lime provide calcium and magnesium to the plants and also improve the efficiency of applied rock phosphate. Excess liming may reduce cassava root yields by inducing micronutrient deficiencies. In the case of rotations or intercropping with crops less tolerant to low pH, higher dosages (2–3 t/ha) of lime may have to be applied. Subsoiling to incorporate lime and bring up roots of trees on newly cleared land, a common Brazilian practice, requires further economic evaluation. Many fertilizer trials in Colombia and Brazil show no clear effect of N and K on root yields of cassava, but positive responses to P application have been noted. Phosphorus levels recommended for correction are 100 kg P_2O_5/ha for sandy oxisols and 200 kg/ha for clay oxisols with 60 kg/ha applied in subsequent years. Zinc and sulfur can be applied at dosages of 10 and 20 kg/ha, respectively.

(13) Fertilization studies should be pursued in well-defined ecosystems where cassava is currently produced and fertility or nutritional problems are recognized. In this respect, the need for establishing standardized soil and plant tissue chemical analyses, for determining critical nutrient levels in cassava tissue and in soils, and for establishing their relation to fertilizer application levels are topics for further research. To do this, adequate laboratory facilities are required, but are lacking in many places. Fertilizer trials should also be

carried out on crop rotations involving cassava to measure residual effects on subsequent crops and on the stability of cassava root yields. It may be necessary to develop separate recommendations for large plantations and for smaller producers with limited resources.

(14) Research into ways of reducing fertilizer use or cost should be intensified. Possibilities are the effective use of mycorrhiza and of N-fixing bacteria in cassava as well as the continuation of the search for cheaper sources of macronutrients such as rock phosphate treated to increase P release. Slow-release fertilizers may be useful as well. Fertilization levels should be based on plant response as well as on the nutrient content of roots and plant tops removed from fields. Potassium losses can be reduced by efficient erosion control, by intercropping or rotations with deep rooted plants to bring leached K to the surface, and by leaving plant residues on the field. Legume intercrops with cassava or legume green-manure crops in rotations represent technologies that are now available and that can maintain or improve soil fertility through addition of organic matter to the soil and N fixation. Research to further improve these practices could be fruitful.

(15) Phytosanitary practices to avoid introduction and/or spreading of diseases and pests in any region must be observed and specific recommendations are available. Attention was drawn to the danger of previously unimportant pests or diseases reaching epidemic proportions in large plantations. This situation should be closely monitored. Research in biological control was stressed.

(16) For medium- and large-scale plantings in most regions of the world, chemical weed control is likely to be more economical than hiring labour for hand weeding. A large group of selective preemergent herbicides have been identified for cassava and specific recommendations for their use under different crop and soil conditions are available. Diuron, Alachlor, and Fluometuron, alone or in mixture, are the most commonly used. For the small producer who may not have the capital to purchase herbicides, use of family labour for hand weeding will likely be most feasible. Cultural weed control practices including appropriate planting density, use of green covers or intercrops, and mulching with crop residues were other alternatives stressed by participants in the workshop for both large and small producers.

(17) The need to standardize terminology was discussed. It was recommended that the words "stake" or "stem cutting" be used rather than "cutting" or "seed" to refer to cut-up planting material; that "sprouting" be used instead of "germination"; and that cassava yields be expressed as "root" yields (in t/ha) rather than as "tuber" yields.

Agronomic Practices for Cassava Production: a Literature Review

Julio Cesar Toro M. and Charles B. Atlee[1]

This paper reviews the main agronomic practices for cassava. Cassava production requires good soil preparation, and, specifically, soil drainage must be adequate. The stakes must be fresh and come from mature healthy plants from which the most lignified part of the basal stem is preferred. The stakes' quality and size are of fundamental importance if high yields are expected. Stakes with signs of cankers, galls, tumours, galleries, or insect infestations should be eliminated, and 30-cm stakes are highly recommended.

Planting on the flat can only be done in areas where root rot is not a serious risk. The vertical planting position is generally recommended, especially in regions with erratic rainfall because it ensures better contact with available moisure, thus provoking faster sprouting. It also gives better and more uniform distribution of roots, and, hence, better anchorage and protection against lodging. The most recommended planting time is the beginning of the rainy season, but in areas where plant diseases are prevalent, planting is usually done at the end of the rainy season.

In general, poor soils show good response to plant population increases, but in rich soils the response to increases in plant population depends on the growing habits of the varieties. For most cassava production, 10 000 plants/ha is recommended unless local research indicates otherwise. Proper selection and treatment of planting material will ensure a sprouting percentage so high that no replanting is needed.

Good weed control, either manually or chemically, is probably the most important factor in obtaining high cassava yields. There are about 19 selective herbicides recommended for cassava. Because of its exceptional ability to extract nutrients from the soil, cassava is usually the last crop to be planted in a rotation scheme. It is advisable to leave the land fallow or rotate following the second or third consecutive harvest, especially in medium-to-poor fertility soils.

It is concluded that the most important cultural practices for cassava production are the selection of healthy and mature 30-cm stakes and good weed control. These practices apply everywhere.

The aim of this literature review is to present a more thorough and up-to-date coverage of the main agronomic–cultural practices used to produce cassava in various parts of the world. No effort has been made to list all references, only selected ones mostly published during the past 20 years. Both fertilization and multiple cropping have been omitted.

Much of the literature is repetitive; however, some excellent work has been done during the past 10 years with the emphasis on cassava research at several national and international research centres. Until recently most agricultural researchers had overlooked cassava, even though it is the seventh most important crop in the world. One reason is that it is primarily a subsistence crop grown in tropical countries (Nestel and MacIntyre 1973). Although grown in more than 60 tropical countries, it has assumed major importance in only six countries that account for nearly two-thirds of the world production.

Although experimental yields greater than 70 t/ha have been obtained, the average yield of cassava worldwide is only 9.4 t/ha. Cock (1974) has suggested that yields in farmers' fields are low because of the lack of suitable varieties and poor agronomic practices.

Cassava is an extremely efficient producer of

[1]Cassava Program, CIAT, Cali, Colombia and Crop Science Department, California Polytechnic State University, San Luis Obispo, California, respectively.

carbohydrates. It is a native of tropical America, tolerant to drought, grows fairly well in poor soils with low pH, and is relatively resistant to disease and insect pests. It has no precise maturity and can be left in the ground and harvested nearly any time of the year, thus being a good security against famine. Its potential yield is greater than for other crops that have been researched extensively. Production of calories per hectare per day is higher than for any other staple food crop. Its foliage can produce up to 5 t of crude protein per hectare a year (Moore 1976). According to recent FAO projections for cassava, present world production is about 110 million tonnes, equal in dry matter to nearly 40 million tonnes of grain (FAO 1978). Of this production, approximately 60% is used for human food. It is an important staple in the diet of more than 500 million people. The rest is used as livestock feed or is converted to starch or alcohol for industrial purposes. Cassava is extremely perishable when harvested fresh, but if dried or processed it can be stored like most cereal grains. Although not much cassava is consumed in Thailand, it has become that country's major export crop after rice.

Brazil, the largest cassava-producing country, is presently growing a considerable amount of cassava for alcohol production to be used as a gasoline supplement.

Land Preparation

As for any other crop, cassava production requires good soil preparation. Land preparation practices vary considerably, depending mainly on climate, soil type, vegetation, topography, degree of mechanization, and other agronomic practices (Seixas 1976).

Where no mechanization is available and cassava is grown as the first crop in forest clearings, no preparation is required, other than removal of the forest growth by cutting down small trees, shrubs, and vines, and cutting off the branches of large trees to admit sunlight. Trees and bushes are piled and burned at the end of the dry season (Viegas 1976). When the first rains soften the ground, the soil is loosened with a hoe, planting stick, or sharp instrument, so that the cassava stakes can be easily planted. Grace (1977) reported that the layer of ashes left after burning increases the amount of potash available to the cassava crop.

Where mechanization is available, many cassava growers plow and disk the land to prepare a good seed bed, aerate the soil, and control weeds. In Brazil a common practice is to open furrows 10–20 cm deep so that stakes can be planted horizontally. Ribeiro Filho (1966) has suggested that on steep land these furrows be made on the contour to prevent erosion, a serious problem in sandy soils, especially during the first few months of the crop. Plowing and the first disking should be about 30 days before planting (EMBRAPA/EMBRATER 1976). The second disking should be done just before planting to improve the soil condition and eliminate weed seedlings.

Tineo (1976) has recommended plowing to a depth of 25 cm and then harrowing. In poorly drained soils, ridges should be 15 cm. According to Diaz (1978), in heavy textured soils where danger of root rot exists, cassava must be planted on ridges in accord with experimental results obtained at the CIAT Cassava Program.

Seixas (1976) found no significant difference in cassava yields from soil plowed to depths of 10 cm, 15 cm, or 20 cm, but results could be different in heavier soils.

Normanha (1976b) has suggested that plowing and disking should loosen soil to a depth of at least 20 cm, the depth at which most roots grow. This provides for easy root penetration.

In light, sandy soils, land preparation requires a minimum energy expenditure, and planting is on the flat. However CIAT (1976) has reported that planting on ridges makes harvesting easier, even though yields are sometimes slightly lower than on the flat. Tractor time is 8.40 h/ha for flat planting compared with 12.60–15.33 h/ha for ridges, depending on the height and shape of the ridge.

Santos (1967) found that the percentage of sprouting and yields of cassava were significantly influenced by the method of land preparation. The ordinary method, consisting of harrowing, plowing, harrowing, and making furrows before planting, gave the highest percentage of sprouting and the highest yields (17.6 t/ha). The harrowing-plowing-planting treatment followed (14.9 t/ha). Next were the plowing-planting and harrowing-punching-hole treatments, yielding 15.5 and 10.6 t/ha respectively.

Land preparation, according to Tan and Bertrand (1972), is usually started in the dry season, except in regions with a very humid climate. In the latter, land is prepared at the end of the "heavy rain" season, and stakes are then planted at the beginning of the dry season during which they can take advantage of the lighter rainfall for early root development. Also in lower rainfall areas, earlier plowing is sometimes necessary because the soil is too dry and hard for tillage during the dry period.

In large plantings, the land is usually prepared as for maize; the field is plowed to a depth of at least 20 cm and is then disk harrowed. Planting is done in rows on the flat surface, although heavy soils in humid areas demand "banking" or making beds on ridges at least 15 cm high so that drainage is improved and root rot minimized. In some cases a second plowing is needed before the harrowing. Many farmers in Southeast Asia plow to a depth of only 15 cm, but this practice frequently results in a decrease of root yield.

Storage of Stakes

For best results in any cassava production enterprise, fresh stakes from mature plants are ideal. However, when they are not available because of cold, prolonged drought, or even excess moisture, many producers have to depend on the reliability of methods to preserve them. Common storage practices usually cause poor sprouting and reduce plant vigour. Long storage causes loss of moisture and exposure to the attack of pests.

Bertoni (1945) indicated that, in Paraguay, stakes stored in a dry place maintained their viability after 5 months. He also stated that a sample of stakes that showed sign of a rotting disease were used as planting material after 6 months of storage in a wood house during the dry season.

Mendes (1949) recommended that stakes be piled in a well-ventilated, shaded area under trees or a straw roof where direct sunlight and dampness are avoided. With this method, stakes have been kept in southern Brazil for 3–5 months without deterioration.

Kiernowski (1950) in Argentina used three cassava varieties stored in straw piles, straw clamps, damp straw huts, dry straw huts, and dry, shaded areas and found that storing in damp straw huts and dry straw huts gave the best results. He also concluded that the response to storage varies according to variety and moisture and to the method of placing stakes under straw.

Stephens (1965) stated that, for any storage method, some factors must be kept in mind: stakes must be mature when stored; stakes must not be stored wet or allowed to get wet; and stakes must be covered lightly at first so that surplus moisture can escape and covered more heavily later as protection against the cold.

Sanchez and Rodriguez (1967) studied three methods to preserve cassava during winter in the province of Misiones, Argentina. Stakes were stored vertically and horizontally in a straw hut, in a forest, and in an open field. In all cases stakes were covered with soil, straw, or both. The stakes that were stored horizontally and completely covered with soil in a straw hut were preserved best.

Krochmal (1969) stated that uncut stems are usually stored in shady, well-ventilated areas. In southern Mexico the bundles of stakes are kept upside down under mango trees for as long as 8 weeks. In the south of Brazil, stakes are stored up to 8 weeks, many times horizontally in the open during the cool dormant season (July and August).

In India, stakes are tied in bundles and stored upright in shade or ventilated sheds for up to 6 weeks. If the crop is harvested during heavy rainfall, storage is limited to 10 days.

CIAT (1972) found that stakes kept at 4 °C for 29 days did not sprout, whereas stakes with both ends protected with a fungicide were viable for 65 days. When the tips of the stakes were immersed in liquid wax, the viability was increased to 85 days; in this case, wax was removed at the time of planting.

Castellar and Mogollón (1972) mentioned that in Caribia, Colombia, stakes of 30 and 50 cm covered with banana leaves were stored for 40 days with optimum results. The viability of stakes longer than 30 cm was improved when the tips were dipped in wax.

CIAT (1973) cited findings that stakes longer than a metre have been kept for up to 3 months with the central portion viable; however, stakes shorter than 25 cm deteriorated rapidly. Also cited were findings that stakes with paraffin-waxed ends, when compared with unwaxed stakes in an investigation of moisture loss, did not exhibit reduced fresh weight. Storage position did not affect overall storage behaviour, although stakes stored in the inverted position had delayed bud breaking and horizontally stored stakes produced a larger proportion of shoots from nodal buds than did stakes in either vertical or inverted positions. The moisture content of stakes fell from 67 to 46% after 50 days storage at room conditions. Waxing was not recommended for storage.

CIAT (1974) showed that long stakes wrapped in sacking and stored in a palm-thatched shelter maintained viability better than short or unprotected ones. After 2 weeks, shoots appeared from the apical end of the stakes. The shoots grow, thus exhausting the reserves of the stem and transpiring water.

CIAT (1978) treated 70- and 20-cm stakes of two varieties (one with good sprouting ability and the other with poor ability) by dipping them in Bavistin and Orthocide (2000 ppm a.i. each) or Daconil and Manzate (4000 ppm a.i. each) and found varietal differences in sprouting after storing them in shade. It was concluded that treatment with fungicide prevents losses due to storage.

Lozano et al. (1977) recommended that the storage area should be well-shaded with some light but not excessive relative humidity (about 80%) and with a moderate temperature (20–23 °C). An additional treatment before planting with fungicides favours sprouting even more. He also indicated that although it is not known whether there is varietal resistance to factors affecting stakes during storage highly significant varietal differences have been found.

CIAT (1979) to solve some of the stake-storage problems found that dehydration was prevented by storing stakes in polyethylene bags or by treating with sodium alginate (Agricol), a water-soluble gel. A dry film of this gel allows oxygen interchange and prevents water loss. To avoid damage by insects and diseases, CIAT treated stakes before storage with fungicide-insecticidal solutions. Ninety percent of the 20-cm stakes rooted, and buds sprouted after 12 weeks of storage when treated with Captan/BCM and kept in polyethylene bags at room temperature. About 95% of the 20-cm stakes from long stems (70 cm) rooted, and buds sprouted when stored for 10 weeks on a dry floor at room conditions (24 °C, 80% RH) after treatment with Captan/BCM (2000 ppm a.i. each). Similarly, 90% of the 20-cm stakes rooted, and buds sprouted after 90 days of storage when they were dip treated in a Captan/BCM (3000 ppm) plus sodium alginate (10 000 ppm) solution and kept at room conditions. Treating stakes immediately after harvest regardless of later storage time increased yield of fresh roots per hectare.

Correa (1977c) for the state of Minas Gerais, Brazil, recommended that, when storage is necessary, long stems be placed in a vertical position and the 10-cm base covered with soil and straw as protection against desiccation.

Stake Size

In any production system, size and quality of the stake are of fundamental importance if high yields are expected. According to Lozano et al. (1977), the quality of the stake per se is determined by the age of the stem used, the number of nodes per stake, the thickness of the stake, the size of stake, varietal differences in sprouting, duration of storage, and the extent of mechanical damage to the stake when it is being prepared, transported, stored, and planted.

A cassava plant may be obtained from a very small stake, with only one bud (Cock et al. 1976), but the possibilities of sprouting under field conditions are very low especially when soil moisture is deficient. Celis and Toro (1974a, b) indicated that early development is affected if planting is done in poor soils because the nutritional reserves are insufficient in a small stake for the initial growth stages. They also said that the smaller the unburied portion of the stake, the tougher the competiton with weeds. The advantages of using very long stakes, i.e. 60 cm long, are higher initial height of the plant and, hence, greater shading of the soil surface, which increases the ability of the cassava plant to compete with weeds.

The length of stake commonly used by farmers is 15–25 cm, which seems appropriate unless a field trial that includes production costs indicates a more convenient size. It has to be kept in mind that economic aspects as well as practical considerations about handling the stake may affect the size of the propagating material.

CIAT (1975), working with local varieties in three different locations using 20-, 40-, 60-, and 80-cm stakes planted vertically, obtained the best results with 40-cm stakes without irrigation.

Gonzales (1973) in Jusepin, Venezuela, using 10-, 20-, 30-, and 40-cm stakes planted horizontally, vertically, or in an inclined position in rain-fed conditions for 2 years found no difference that could be traced to planting positions but found that 40-cm stakes always gave the highest yields. In contrast, CIAT (1979) using 20-, 40-, and 60-cm stakes planted vertically at the CIAT-Palmira experiment station under irrigated conditions found that 20-cm stakes yielded significantly better than the other two. Rosas (1969) in La Molina, Peru, using three planting positions and stake lengths of 10, 20, and 30 cm found no yield differences due to planting positions but found that the 10-cm stakes gave the highest yield. Silva (1970) reported that experiments in the state of Santa Catarina, Brazil, with stake lengths of 10, 15, 20, 25, and 30 cm have indicated that 30-cm stakes are superior. Normanha and Pereira (1964) recommended stakes, 20–25 cm long, planted horizontally, 10 cm deep, for Brazil in general. Chan

(1970) in Malaysia found no differences in yields using stakes 8, 15, and 23 cm long.

Gurnah (1974) in two experiments carried out during 2 years in the forest zone of Ghana with adequate rainfall (1080 mm) using stakes of 2, 3, 4, 5, 6, 7, and 8 nodes found that yield increased with the number of nodes up to five. An increase in the number of nodes beyond five per stake did not affect yields. The longer stakes had more buried nodes than did the shorter ones and presumably produced more stems and leaves and in turn higher yields. Also, Donkor (1971) observed that when more nodes are buried, more roots and stems are initiated. However, it must be pointed out that the stakes used in his experiments were from freshly cut stems. If the stems had to be transported over long distances or stored for a long time before planting, hardiness and ability to survive storage would have been important, the more mature basal and middle stakes probably giving better sprouting and possibly better yields. During Donkor's experiments, there was adequate, well-distributed rainfall. It is likely that if there had been no rain for a long period after planting, the types of stakes also would have made a difference, as top stakes are most likely to suffer from lack of rain. In the forest zone, where rainfall is plentiful, any type of stake can be used reliably.

Jeyaseelan (1951) working in Ceylon (Sri Lanka) with basal and apical stakes, 15 and 30 cm long, and investigating horizontal and vertical planting positions found that best yields were obtained with 30-cm stakes from the basal part, planted vertically.

Rodriguez and Sanchez (1963) in Misiones, Argentina, in a 3-year study using 30-cm stakes and two planting positions (inclined and horizontal) and comparing the results with those from 10-cm stakes planted horizontally, found that the 30-cm stakes gave higher yields, as did the inclined position, although the latter made harvesting difficult.

Conceição and Sampaio (1973a) for 3 years in Bahía, Brazil, used 10-, 12-, 15-, 20-, 25-, and 30-cm-long stakes from 12-month-old plants in sandy, clay, loam latosol with 1196 mm of rain and 24 °C. Stakes were planted horizontally, 10 cm deep. They found that high yields were obtained with 20-, 25-, and 30-cm stakes.

Jennings (1970) suggested that long stakes gave higher yields than short ones. He recommended 30- and 45-cm-long stakes (moderately thick), taken from the basal part of the plant rather than from terminal parts.

Planting Methods

Whatever planting method is used, good sprouting of the stakes requires adequate soil moisture and good soil preparation. Land preparation and the corresponding planting methods depend primarily on soil type and climate. Toro et al. (1978) reported that studies carried out by CIAT, on the flat plains of Colombia, showed that flat planting is advantageous when done during the dry season. Ridge planting was desirable during the rainy season. A "bed" system, developed at CIAT, uses a flat-top ridge. The beds are made by a shaper attached to a rototiller; therefore only one operation is needed to prepare the land for planting. (Beds or ridges are not recommended for sandy soils because they will not hold their shape, and, in any case, such soils have good drainage.) Beds are somewhat more practical than ridges for intercropping cassava with beans or cowpeas, which can be planted mechanically at the same time as cassava on a heavier soil. When machinery is not available to make ridges or beds, cassava can be planted on the top of a cone-shaped hill or mound built manually with a hoe (Toro et al. 1978).

As Normanha (1976b) also indicated, heavier, more compact soils should be prepared in beds or ridges. Heavy soils that seal or waterlog have a detrimental effect on cassava during the rainy season because of poor aeration. Without adequate oxygen, the cassava cannot form storage roots, probably because starch accumulation needs large quantities of free oxygen.

In 1976 Conceição reported that horizontal planting, 10 cm deep in furrows, facilitates commercial harvesting and reduces weed problems. Ezeilo et al. (1975) found that in Nigeria cassava is grown on lighter soils and that 77% is planted on hills, 11% on ridges, and 11% on the flat. In Malaysia, Lulofs (1970) reported that planting on the flat is satisfactory but ridging may give a more even stand, easier harvesting, and better erosion control.

Lozano and Terry (1978) recommended that, in areas where rainfall is more than 1200 mm, clay soil should be prepared in ridges to promote better drainage, which improves crop stand and yield considerably. Yield losses of 80% caused by root rots have been reported. However, Koch (1916) found no significant difference in yield between planting on the flat or on ridges, and Grace (1977) wrote that some experiments have shown ridging to produce somewhat lower yields than flat planting. Harper (1973) also reported that planting on ridges in Thailand produced lower yields than did flat planting. In one experiment with commercial-sized plots conducted in the loamy soils of the Caicedonia area, CIAT (1976) reported similar results; however, ridging reduces weedings and facilitates harvesting.

Krochmal (1969) stated that planting on furrows or ridges is a rare practice and not one to be encouraged because machine planting is impossible with such systems and the costs of the additional operations do not pay off in any increased returns.

Planting Position

Like the literature on planting methods, that for planting position is equivocal, and the most appropriate planting position varies with cassava variety, soil characteristics, and climate.

Galang (1931) in the Philippines using 30-cm stakes of 21 different varieties found that 13 gave higher yields when planted vertically, whereas the remaining eight responded better to an inclined position. After two experiments he concluded that stakes may be planted in either an inclined or a vertical position with practically equal results. But, Fernando and Jayesundera (1942) indicated the significant superiority of vertical planting over horizontal. Later, Rao (1952) stated that vertical planting is superior where rainfall is moderate and that inclined position is adopted where rainfall is more than 1700 mm a year.

Brandao (1959) compared two systems of planting cassava in heavy soil. Basal stakes, 40 cm long, planted vertically, 10 cm deep, yielded 30% more than 20-cm stakes planted 10 cm deep horizontally. The root distribution was different, with roots being nearly 5 cm deeper from vertically planted stakes than from those planted horizontally. The latter were easier to harvest.

Crawford (1961) working in Jamaica came to the conclusion that horizontal planting of 25-cm stakes is best if soil moisture is limited at planting time. If the stakes are covered with 2–3 inches (5–7 cm) of soil, there is less "drying out" and therefore sprouting percentage is improved. Roots originate from a greater number of points along the length of the stake and therefore have more room to develop; they also tend to spread and develop closer to the soil surface, making better use of applied fertilizer and organic matter. Horizontal planting gave higher yields than did inclined plantings (an angle of 15 or 45 degrees).

Loria (1962) in Costa Rica studied three planting positions, horizontal, inclined, and vertical, and found no significant difference in yield although vertical planting produced the highest yield. Similarly, Chan (1970) found no differences in yield from horizontal, vertical, or inclined planting of 15-cm stakes. On the other hand, Krochmal (1969) in the Virgin Islands reported that it would be better to plant 20- or 25-cm stakes with three buds, horizontally at 5–10 cm under the soil surface than to have them inclined. Kunju (1972) indicated that, when stakes are planted on ridges, vertical planting is always found to be better.

Harper (1973) in Thailand found that the planting position depends on soil and climatic conditions. Generally horizontal planting is carried out in the dry season (October to May), producing more sprouting and greater yield due to the fact that roots are produced from more growing points. Also roots tend to grow nearer to the surface of the soil, which makes harvesting easier. Vertical or inclined planting is used in areas where rainfall is high during the wet season (May–October) or where horizontal stakes would rot, such as in areas with high soil moisture.

Gonzales (1973) in Venezuela made a study involving two tests on size and planting position. He used four sizes: 10, 20, 30, and 40 cm and three positions: vertical, inclined, and horizontal. In both tests, the 20-, 30-, and 40-cm stakes were significantly superior to 10-cm stakes, and he, therefore, recommended continued research using 20- to 40-cm stakes. With respect to planting position, the results of the first test gave 15.0, 13.7, and 12.0 t/ha respectively for horizontal, vertical, and inclined positions. Although the horizontal and vertical were superior there was no significant difference between the two. In the second test yields from the three positions were not significantly different, ranging from 22 to 23.8 t/ha. The lower yields of the first test may have been due to deficient rainfall.

In other work on planting position, some workers found no significant difference in yield but a decided difference in depth and root distribution (Gurnah 1974). Vertical planting produced roots that were deeper and closer together, whereas horizontal planting produced shallow roots distributed along the length of the stake.

Cock (1974) stated that studies on planting position do not show consistent trends.

Chew (1974), with cassava grown in Malaysian peat soils for 2 years, used horizontal, inclined, and vertical planting and found no significant difference in yield from the three positions. However, he recommended horizontal planting because it provides better protection against desiccation of stakes and also gives better sprouting.

Conceição and Sampaio (1975a, c) undertook an experiment involving four planting systems with four cultivars. The effect of the planting system was not statistically significant; consequently it was recommended to plant on the flat using 20-cm stakes planted horizontally at a depth of 10 or 20 cm because it would be less expensive for mechanical planting.

Wahab et al. (1977) found no significant difference in yields from manual and mechanized horizontal planting in Guyana.

In Colombia, Diaz et al. (1977) observed that cassava was widely planted in the vertical position in only one of the five cassava-growing areas they studied. This region was characterized by sandy soils with a prolonged dry season (up to 4 months) and a mean annual rainfall of 1200 mm.

According to Grace (1977), under low rainfall conditions, vertical planting may result in the desiccation of the stakes, whereas in areas of higher rainfall, horizontally planted stakes may rot. In general, horizontal planting, 5–10 cm below the soil surface, is recommended in dry climates and when mechanical planting is used. This system makes manual harvesting easier too. Vertical planting is used in rainy areas and inclined planting in semi-rainy regions.

Castro et al. (1978) determined that neither the cut angle nor the planting position of the stake had a significant effect on yield. With the right-angle cut, the roots were distributed uniformly around the perimeter. With horizontal planting, harvesting and separation of the roots was easier compared with vertical or inclined planting. A right-angle cut and vertical planting position were recommended because of a slight tendency toward higher yield. The horizontal position was recommended for mechanized planting when soil moisture is adequate.

Onwueme (1978a) by using 20- to 35-cm stakes planted vertically upright and inverted found that yield was significantly higher for the upright planting.

Celis and Toro (1974a, b) recommended that for vertical planting at least four buds should be underground for good sprouting. In this position, roots tend to form at the lower end of the stake and are distributed radially, more or less uniformly. Inclined planting means inserting the stakes in the soil at a 45-degree angle. In this case the roots tend to follow the same direction of the angle at which the stake is planted. Some farmers think that harvest labour is easier with this method because of the position of the roots. Horizontal planting involves placing the stake horizontally, usually in a furrow, and burying it completely. This planting position lends itself well to mechanical planting. In this position roots tend to form at the butt end of the stake. When stakes are long (30–40 cm), roots may form along the sides at the nodes.

In tests at CIAT, sprouting and emergence of stakes under field conditions were always more rapid with vertical planting than with any other method. Even though there are good reasons and clear advantages to planting cassava stakes vertically, there are also some advantages to horizontal planting: (1) horizontal planting is easier; (2) there is no need to worry about planting stakes upside down, which Bolhuis (1939) showed to be undesirable; (3) there is no need to stoop or bend over (Odigboh 1978); and (4) the roots are shallower and easier to harvest. However, some of the obvious disadvantages are: (1) under extremely adverse climatic conditions, the shallow (5 cm) planting allows more heat damage, more exposure of roots to erosion effects, and more lodging from wind (Koch 1916 and Castro 1979), due to poor anchoring in the ground; (2) deeper planting (10 cm) can cause slower sprouting and emergence, resulting in more weed competition (Castro 1979), and during weeding more damage to stakes that have not yet emerged (Ribeiro Filho 1966); and (3) sometimes lower commercial yields are produced than with vertical or inclined plantings.

In sum, experience in many cassava-growing areas of different countries has indicated that planting position should be decided according to the following criteria:

(1) In regions of medium to heavy soils with adequate rainfall (1000–2000 mm/year) it does not matter whether stakes are planted horizontally, inclined, or vertically because the moisture will be adequate for sprouting of the buds.

(2) In areas of sandy soils or erratic rainfall, vertical planting is safest. In this case, 20-cm stakes will have at least 10–15 cm in the soil, and thus have better contact with available moisture. When stakes are planted horizontally in such regions, the buds will rot because of the heat, which is always greater in the soil than in the surrounding air. In the case of vertical planting, the stakes serve as a heat diffuser (Lozano personal communication 1975).

Planting Dates — Time of Planting

The most common planting time for cassava is at the beginning of the rainy season when competition for labourers for planting is at its peak. In areas with adequate temperature and soil moisture during the dry season, planting can be done at almost any time when labour is available. Planting in the dry season also reduces disease problems and increases yields. It is advisable to plant after the first well-defined rains to avoid losing the plants. Research done by Normanha and Pereira (1947) in São Paulo, Brazil, indicated that planting cassava during the normal harvest (May–July) produced the highest yields and starch content. This timing would also solve the problem of storing planting material and would result in less soil erosion than planting during September and October after rains begin. Correa (1977c) stated that in other areas of Brazil it is advisable to plant at the beginning of the rainy season, which in Minas Gerais is October–mid-December, or during the rainy season in drier areas such as Bahía (April–June). Albuquerque et al. (1974) cautioned against planting during October–January in eastern Para in the Amazon Valley because that is the wettest period and rotting can be a problem. Viegas (1976) however, recommended October planting in northeastern Brazil because of the long season (12–24 months). In southern Brazil, all cultivars should be planted in August (or October in dry years).

Silva (1979) recommended planting at the beginning of the rainy season, but Ribeiro Filho (1966) indicated that earlier planting is recommended by Normanha and Pereira for São Paulo and Drumond for Belo Horizonte.

Many factors that could influence soil moisture such as the texture of the soil, rainfall, relative humidity, temperature, and wind; in heavy, poorly drained soils excess moisture encourages root rot (Oliveros et al. 1974). Lozano and Terry (1978) stated that appropriate planting time may reduce the incidence of disease. For instance, planting at the beginning of the rainy season ensures good establishment and ensures sufficient growth of the canopy to provide shade during the dry season, approximately 4 months after planting. Because of the dry environment (in spite of poor air circulation and high relative humidity between plants), the microclimate will not be favourable to pathogens. For this same reason, planting has been recommended at the end of the rainy season in the eastern *llanos* of Colombia.

In many cassava-growing areas, rainfall is evenly distributed throughout the year and offers the possibility of several different planting dates with only minor differences in yield especially where soils are well drained yet maintain moisture. Two planting dates have been recommended for the Philippines and Colombia because of two rainy seasons per year.

According to Correa (1971), the timing of planting is the most important production factor. Zijl (1930) also stated that planting dates markedly influence production and recommended November planting for Java (Indonesia). Celis and Toro (1974a, b) commented that probably the most important factor related to time of planting is lack of moisture, which during the first 20 days after planting may cause serious losses in sprouting.

Viegas (1976) stated that although planting should be done at the beginning of the rainy season it is important to plant only on a clear, dry day. One problem with waiting until after the rainy season is well under way is that good propagation material may be difficult to find. If stems have already started to sprout, the sprouts are easily broken off in handling, and if stakes have been stored for a long time, they become dehydrated and lose their sprouting vigour.

An experiment, reported by Rodriguez et al. (1966), was conducted in the Misiones province of Argentina, over a 3-year period. The findings were that one variety was best planted early (August–September) and harvested in May and that another was best planted late (October–November) and harvested in June. In other words, specific varieties may each have different optimum planting and harvesting dates. This is probably the reason that many subsistence farmers plant several different varieties throughout the year so that they can have cassava to harvest at any time.

In 1977, Grace indicated that time of planting is influenced by both weather conditions and the availability of planting material. Planting is sometimes divided between the two rainy seasons, but is usually carried out throughout the year in regions with year-round rainfall. It is desirable to plant and harvest during approximately the same season to avoid storing the stalks for a long time. Experience has shown that starch production in the cassava plant is best when planting takes place at the beginning of the rainy season.

Ninam et al. (1977) found that in Kerala, India, cassava can be grown all year and that for maximum root yields, planting should be done in April. The second best season for planting is September. Nair (1978) recommended April–May as the best time for planting in Kerala and Tamil Nadu where the climate is warm and rainfall is 1500 to 2000 mm/year distributed evenly.

Planting Depth

Normanha and Pereira (1950), using three depths (5, 10, and 15 cm) and two planting seasons during 3 years, concluded that under hot dry conditions stakes planted 15 cm deep sprouted faster than did those planted at shallower depths perhaps because of increased moisture at the 15 cm depth. The opposite was true when temperature and moisture were adequate. The harvest was much easier for stakes planted at 5 cm deep than for those planted at 15 cm because of the rooting depth of the latter. The yields were 18.2, 16.5, and 13.2 t/ha for stakes 5, 10, and 15 cm deep, respectively. The planting depth of 5 cm was quite advantageous but had drawbacks, such as the lack of protection against erosion and lodging, that made a 10-cm planting depth more suitable.

Campos and Sena (1974), to measure the rooting depth of cassava, planted 20-cm stakes in rows 10 cm deep in a horizontal position and spaced 1.00 × 0.60 metres apart. The results showed that the roots reached depths of 90 and 140 cm at 140 and 365 days, respectively. Within the 30-cm depth were found 95.3 and 96.4% of all roots, and of these 65.6 and 85.7% developed in the top 10 cm of soil.

Conceição and Sampaio (1975a, c) recommended the flat planting of 20-cm stakes, 10–20 cm deep in a horizontal position, because this lowers the cost per hectare for mechanical planting.

In Brazil it is recommended that cassava be planted in continuous rows horizontally 10–15 cm deep and that animal- or tractor-powered machines be utilized.

Holguín et al. (1978) found that, under optimum conditions, such as adequate soil moisture and good quality treated stakes, planting depth did not affect the growth or yield of cassava planted vertically. The 10-cm planting depth for the vertical position was easiest for both planting and harvesting. This study should be repeated in light sandy soils with little moisture because under adverse conditions these soils become extremely hot and dry at a depth of 5 cm and would create a most unfavourable environment for sprouting and rooting of cassava stakes (Normanha and Pereira 1950).

Ribeiro Filho (1966) suggested that deeper planting makes harvesting more difficult, and Celis and Toro (1974a, b) noted that stakes can be planted shallow or deep in any one of several positions. A good practical rule is that cassava stakes planted in dry sandy soil should be inserted relatively deep, whereas those in moist, heavy soil require shallow planting. In the latter case, it should be remembered that a deep planting will make harvest difficult and increase production costs.

In 1972, Tan and Bertrand commented that depth of planting must be regulated in terms of environmental conditions. Too much exposure of the stakes in areas where soil moisture is below optimum can result in poor stands and consequently low yields.

Mechanized Planting

According to Normanha (1970), the highest degree of cassava crop mechanization in Brazil has been reached through the use of a two-wheeled mechanized cassava planter, made in Brazil, which simultaneously accomplishes furrowing, fertilizing, horizontal planting, covering of stakes, and firming of the soil. It is tractor pulled and plants two rows at a time.

At present, the need for a more efficient machine for planting is becoming very important, especially where large areas have to be planted in a short time. The old Sans two-row planter is very heavy and requires stakes already cut. This latter "drawback" may be useful because the stakes can be treated prior to planting. Massey Ferguson also has a two-row planter, lighter than Sans. This planter opens up the furrow, cuts the stakes to the size desired, deposits them in the furrow, places fertilizer on either side of the stakes, covers them with soil, and compacts the soil if required. It has a planting capacity of 3–4 hectares per day. The Delfosse machinery manufacturers in Montes Claros, Minas Gerais, are engaged in developing cassava planters for 4–6 rows.

Monteiro (1963) reported that the Sans planter was tested at Piracicaba, Brazil, and it did an almost perfect job. It operates at normal tractor speed even on fairly steep land. Using it, eight persons can plant 10 ha/day, whereas 30 persons are needed to plant the same area by hand.

Leihner (1979) stated that implements of the vegetable or tobacco-transplanting types should be looked at for possible adaptation to vertical planting. Mechanization in grain–legume planting has existed for a long time and cannot be considered as a technical problem but an intercrop planter would have to combine the different elements of the single crop planters into one machine. Cock (personal communication 1978) indicated that the cassava program of Cuba has developed a planter prototype for vertical planting.

According to Odigboh (1978) the manual planting of cassava stakes, in a vertical or inclined position, is an arduous and back-breaking operation and constitutes one of the major factors limiting the development of large-scale cassava industries in Nigeria. So the development of a new two-row cassava planter in that country may be particularly important. The machine is fully automatic, tractor-drawn at speeds up to 10 km/h. It plants stakes of diameters between 2 and 5 cm and excludes smaller diameters, which have lower viability. Stakes 25 cm long are planted 17 cm deep at inclinations of up to 80° to the horizontal, depending on tractor speed. Spacing is 0.9 m on small ridges that are 0.9 m apart. The metering mechanism is driven by the drive wheels. The machine is quite sensitive to the quality of field preparation, especially at high speeds; 6 km/h is recommended. The within-row plant spacing is practically independent of planter speed. Makanjuola (1975) reported that several units of this automatic planter can be mounted side-by-side for planting more than one row at a time. The machine can be manufactured in Nigeria except for the ridge disks and bearings.

Schulte et al. (1973) reported good results with a New Holland vegetable transplanter, which planted an average of 0.28 ha/hr. He indicated that it should be possible to develop a transplanter that would make ridges and plant the cassava stakes in one operation.

Plant Population

Optimum plant density of cassava is highly dependent on edaphiclimatic factors, cassava varieties, soil fertility, cultural practices, and the final utilization of the roots. Calderón (1972) working with two varieties in a fertile soil at populations from 10 000 to 30 000 plants/ha found that yield increased with population in only one of the varieties. CIAT (1976) reported that optimum plant population per unit area depends on the size of the plant. Two short and two tall varieties with different branching characteristics were selected and planted at CIAT at densities between 2500 and 40 000 plants/ha harvested at 12 months. It was found that total root yield increased as plant population increased. This is a good characteristic for industrial cassava cultivation. However, for commercial fresh consumption optimum plant population was 10 000 plants/ha for short and tall varieties of erect type and 5000 plants/ha for tall branched varieties.

Experiments conducted by CIAT (1975) in different zones showed that optimum plant population changed according to ecologic conditions. In general, poor soils show good response to plant population increases, whereas in rich soils the response to plant population increases depends on the growing habit of the varieties. In 1970, Silva reported that in the southern state of Santa Catarina and the Sete Lagoas region at Minas Gerais it is convenient to plant from 16 666 to 20 000 plants/ha in soils of good fertility.

Normanha and Pereira (1963) also recommended from 16 666 to 20 000 plants/ha in low fertility soils of the state of São Paulo even if plants are fertilized and 13 888 plants/ha in fertile soils due to the more vigorous growth in this type of soil. Nunes et al. (1976) reported that using nine populations in three municipalities of the state of Rio de Janeiro with low fertility soils, he found that 20 000 plants/ha gave the best result for total roots. He also concluded that for every 20 cm of extra space yield was reduced by 765 kg/ha. Drumond (1954) found that in the experiment station of Patos in Minas Gerais in fertile soil the best population was 20 000 plants/ha; Mattos et al. (1973) recommended 16 666 plants/ha for the Cruz das Almas region in Bahía for soils of low fertility without fertilizer application. Santos et al. (1972) recommended 10 412 plants/ha for the state of Pernambuco. He also indicated that for the poor soils of the northeast 20 000 plants/ha is recommended in contrast with 13 888 for the good fertile soils of the same region. Albuquerque (1970) has recommended after many years of cassava research 10 000 plants/ha for the low fertile soil of the state of Pará in the Amazon basin, 17 777 for soils of fertility below average, and 4473 for the fertile soils. Mandal et al. (1973) at the Central Tuber Crops Research Institute found that the highest root yield was obtained at 12 345 plants/ha for a branched variety and 17 777 plants/ha for a nonbranched variety during a 2-year study. Consequently, the requirement of spacing for different types of varieties was ascertained. He also found that with increases in shoot numbers from one to two shoots per plant root, yield increased significantly in both branched and nonbranched strains.

Narasimhan and Arjunan (1976) found at Tamil Nadu in India that by adopting wider spacing in cassava at 12 345 plants/ha they could minimize incidence of mosaic. In general, it has been observed that as plant population increases, the total root yield also increases; however, the number of roots per plant, root size, and harvest index decrease, while weed control by competition improves. CIAT (1973) with a systematic fan design planted three varieties at populations ranging from 2000 to 80 000 plants/ha. At the 7th-month harvest, CMC-84 gave its highest yield (18 t/ha) at populations of between 5000 and 9000 plants/ha whereas CMC-49 produced its highest yield (18 t/ha) at between 2000 and 5000 plants/ha. The variety Llanera yielded 24 t/ha between 3000 and 7000 plants/ha so it seems that optimum plant density in cassava changes with varieties. The yield decreases at populations larger than optimum because of the weight reduction in roots.

Tardieu and Fauche (1961) recorded the highest yields of cassava with 10 000 plants/ha; however, Rodriguez et al. (1966) recommended much higher populations 13 300–20 000 plants/ha. Gurnah (1973) obtained the best yield of roots at populations of 18 500 plants/ha planted at 60 × 60 cm and observed that spacing above or below 60 cm reduced root yields in the forest zone of Ghana. Gurnah's optimum spacing of 60 cm was closer than that (90 cm) generally recommended in Ghana (Doku 1969). Takyi (1972) observed that spacings of 90 × 90 cm and 90 × 60 cm on sandy loam in ochrosol at Kwadaso, Ghana, gave significantly higher yields than spacings of 90 × 120 cm, but there were few large roots with the closer spacings. Enyi (1970, 1972) used 90 × 120 cm in experiments on cassava in Sierra Leone, but Godfrey-Sam-Aggrey and Bundu (1972) spaced experiments at 120 × 120 cm in Sierra Leone. Godfrey-Sam-Aggrey (1978) using a multishooted variety in Njala upland soils of Sierra Leone found that increasing plant population to more than 7000 plants/ha decreased all parameters studied except top/root weight ratio, which increased. The observed effects were attributed to competition for environmental resources, because area of land/plant unit decreased as plant population increased.

The literature with respect to optimum plant populations and yields conflicts both among and within countries. Because the growth habits and morphology of the crop, as well as environmental conditions, influence cassava yields, recommendations on plant populations for one variety in a particular environment may not be appropriate elsewhere or with a different variety of cassava.

Replanting

Replanting consists of replacing stakes that for some reason do not sprout 1 month after being planted. If the planting material has been properly selected and treated (Lozano et al. 1977), replanting may not prove necessary. Economic considerations are important because a decision must be made about the percentage of sprouting failure at which replanting is economically feasible. By following a careful selection and treatment of stakes, Toro (1979) was able to get 94% sprouting mean in 28 trials with 38 promising and 10 local varieties in 10 Colombian locations during 3 years covering a wide range of ecologic conditions. According to Tan and Bertrand (1972), if a high yield is desired, stakes that fail to develop should be replaced as soon as possible. Grace (1977) suggested replanting no later than 1 month after planting, when at least 5% of plants fail to sprout.

In Caicedonia, Colombia, Ramon Duque (personal communication, 1979) used long-heeled stakes coming from the first branching of a mature plant for replanting. The stake was planted in such a way that the long part remained inclined (75°), whereas the heel (about 20 cm) was buried horizontally. The length of the stake was always 25 cm longer than the average height of the crop at replanting time. The replanted stakes sprouted rapidly and caught up with the rest producing yields comparable with those from stakes. The use of heeled stakes has been recommended by Hartman and Kester (1968).

Weed Control

Good weed control is one of the most important factors in obtaining high root yields in cassava. According to Ribeiro Filho (1966), it is especially important during the first months after planting and during the rainy season. In 1976, Doll and Piedrahita pointed out that with no weed control cassava yields can be reduced by 50% but with only minimal weed control cassava has the ability to survive, compete, and produce good yields. Nearly all researchers agree about the importance of early weed control when the crop is young and most susceptible to damage from weed competition for light, water, and nutrients.

Gonzales (1976), Delgado and Quevedo (1977), and Doll et al. (1977) reported that weeding represents more than 45% of the cost of production. This cost is almost entirely for labourers, who are at times not available because of other priorities. When weeds are small, they are much more easily controlled than they are later when they may have already produced an abundant seed crop.

The number of weedings necessary for cassava varies considerably in different reports, depending mainly on soil fertility, climatic factors, and varieties. In 1975, Onochie stated that experiments in Nigeria showed that, when limited labour is available for cassava production, it should be used for weed control during the 3rd month after planting. Weeding at this stage was as effective (in terms of yield) as weeding throughout the entire growing period. Santos et al. (1972) recommended 3–5 weedings during the first 6 months and 1–2 times the 2nd year, for the northeast of Brazil; Crawford (1961) suggested 4–5 weedings during the first 12 months in Jamaica.

Ezeilo et al. (1975) reported an average 2–3 weedings in Nigeria, and Diaz et al. (1977) observed 3 weedings within 6 months of planting in Colombia. Tan and Bertrand (1972) recommended weeding as often as needed until the foliage canopy closes; according to Doll and Piedrahita (1976) this process takes 2–4 months. Weeding should begin as soon as weeds start to compete with the cassava. Delgado and Quevedo (1977) suggested the first weeding be done 28–35 days after planting and Montaldo (1966) said 21 days after planting plus other times when weeds begin to be a problem. CIAT (1973) stated that early weedings about 2 weeks after planting may be harmful to young unrooted cassava plants.

The amount of weeds and therefore the frequency of weeding depends on a number of factors such as: planting time and prevailing weather — lower soil moisture encourages fewer weeds (Ribeiro Filho 1966); soil fertility — pH-poor soils or infertile soils may have few weeds (Castro 1979); vigour of planting stock — fresh stakes, carefully selected and chemically treated (Leihner 1979), produce the best results; proper soil preparation — harrowing, waiting 2 weeks, then listing or ridging would eliminate two flushes of weeds (Viegas 1976); planting method — horizontal planting results in slower sprouting of stems, which in turn results in more weed competition (Silva 1971b; Ribeiro Filho 1966); variety, especially growth charactistics (Doll and Piedrahita 1976); spacing — closer planting shades out weeds earlier (Conceição 1975); weed species — some species are particularly difficult to control (Ribeiro Filho 1966); weedseed in soil — good previous crop management prevents weeds from going to seed and therefore reduces weed populations (Ribeiro Filho 1966); and shading by cassava — 3–4 months after being planted, the cassava produces shade that inhibits weed germination and growth (Silva 1971b; Doll and Piedrahita 1976).

Weed control in cassava is traditionally done by hand with a hoe. EMBRAPA/EMBRATER (1976) for Ceara state in Brazil recommended making the first two weedings with an animal or tractor-drawn cultivator, returning with a hoe between plants in the rows. Silva (1979) suggested mechanizing weed control whenever possible, and Delgado and Quevedo (1977) indicated that furrowing and listing with a cultivator is advisable at about 2–3 months after planting because this operation not only controls weeds but improves drainage and facilitates harvesting. Earlier, Ribeiro Filho (1966) had recommended listing during the second and third cultivation but had said that thereafter weeds should be controlled only by hoeing because too much damage is done to the cassava plants by the cultivator.

The use of herbicides in cassava is quite new, but in recent years some excellent work has been done, especially in Latin America. Diaz and Arismendi (1973) in Venezuela obtained the highest root yields with Fluometuron (Cotoran) at 3 kg/ha and Ametrina (Gesapax) at 2–3 kg/ha in a sandy loam soil; however Coelho and Correa (1971) in a heavy oxisol in Sete Lagoas, Brazil, found some phytotoxicity with Fluometuron during early development of the plant. Cunha et al. (1975) in latosolic soils of Cruz das Almas, Bahía, Brazil, found Diuron (Karmex) to be selective. On the other hand, Moody (1972) observed 84 and 62% yield reduction by using Diuron and Linuron (Afalon, Lorox) at 3 kg/ha on sandy clay loam soils in Ibadan, Nigeria.

Jennings (1970) reported that weed control was only necessary during the early growth of cassava and the use of chemicals to control weeds in cassava is uncommon in Africa. In Sierra Leone, Godfrey-Sam-Aggrey and Bundu (1972) suggested 30-day intervals between weedings; Godfrey-Sam-Aggrey (1978) studied the effects of not weeding and of weeding by hand at 30-, 45-, 60-, and 90-day intervals and found that time and frequency of weeding were important in influencing root yield. Delayed weed control depressed root yield. The critical period of competition was in the 45-day weeding interval.

Valles (1977) in Tarapoto, Peru, found the critical period to be between 45 and 60 days and the best treatment to keep the crop weed free during the entire growing cycle. In most cassava-growing areas herbicides are not available and are a considerable expense, initially, to the farmer. According to Montaldo (1966) herbicides should be used if plantings are of a commercial size of 20 or more hectares. In sandy soils extreme caution should be used in applying herbicides. Work done at CIAT (1975) showed that even at low doses, the herbicides leach enough in sandy soils to damage or kill the cassava. Ridging appeared to exacerbate the problem. Some cassava cultivars have been shown to be more susceptible to herbicide toxicity (CIAT 1974). In other soils Doll and Piedrahita (1976) found that Diuron (Karmex) applied as a preemergence spray plus one hand weeding about 60–75 days after planting gave the most economic weed control under CIAT conditions of heavy clay vertisols.

There are a lot of selective herbicides; Doll and Piedrahita (1976) listed 18 herbicides highly selective and 12 moderately selective. Leihner (personal communication 1979) found Oxifluorfen to be moderately selective alone or in mixture with Alachlor. This new herbicide controls both broad leaf and grasses in preemergence. It can be used safely at dosages between 0.5 and 1.0 kg/ha a.i. CIAT (1976) recommended the mixture of Diuron and Alachlor (Lazo) at different dosages, according with soil texture (Table 1), Diuron to control broad leaves and Alachlor to control grasses.

Leihner (1979) recommended the mixture of Linuron and Fluorodifen (Preforan) at 0.5 + 2.5 kg a.i./ha applied in preemergence to cassava intercroppped with dry beans (*Phaseolus vulgaris*).

Irrigation

According to Cock and Howeler (1978), there are few data on the water requirements of cassava, critical periods when water is essential, or the response to irrigation. Their experience with cassava, unfortunately not yet supported by data, has suggested that cassava requires moist soil for sprouting and establishment of a stand. If a drought occurs after the first 2 months of growth, the cassava plant virtually stops growing.

Table 1. Different dosages of Diuron and Alachlor mixture according to soil texture.

	Dosage		
Soil texture	Diuron (kg/ha)		Alachlor (l/ha)
Clay	2.0	+	3.0
Silt loam	1.5	+	2.5
Clay loam	1.5	+	2.0
Sandy	1.0	+	2.0

Under these circumstances leaves fall off, and the plant essentially becomes dormant, whereas other crops like corn, beans, and rice would die. With the onset of rain, cassava utilizes carbohydrate reserves in stems and roots to produce new leaves (Cours 1949). These observations suggest that cassava is an extremely useful crop in tropical areas of uncertain rainfall.

In low rainfall areas, Campos and Sena (1974) found that irrigating cassava affects root distribution. Irrigated cassava had 91–98.5% of its roots in the upper 10 cm of soil, but the nonirrigated cassava had roots as deep as 140 cm with only 28.8% of the roots in the upper 10 cm of soil.

Muthukrishnan et al. (1973) and Smith (1968) both reported decreased yields for cassava when irrigation was applied more frequently than once a week. Cock and Howeler (1978) speculated that too frequent irrigation leads to excessive top growth and reduces yields of many varieties. Hence, cassava appears to be better adapted to low rainfall areas and soils with low water-holding capacity. Cassava, like most other crops, will not tolerate excess water; yields are seriously reduced by poor drainage. Menezes (1958) came to the conclusion that cassava actually has the highest moisture requirements at 4–6 months after planting.

Smith (1968) found that increased irrigation results in lower starch content of harvested cassava — a finding that may explain why many cassava growers try to harvest at the end of the dry season before the rainy season provides enough moisture to encourage a new flush of vegetative growth that uses starch reserves in the roots and stems. For Bahía, Brazil, Conceição (1975) recommended the application of about 35 mm of water every 18 days during periods of little or no rainfall. In addition it was suggested that irrigation just prior to harvest moistens heavy soil enough to facilitate harvesting. Shanmugavelu et al. (1973) reported from India that irrigated cassava nearly always outyields nonirrigated plantings. Best results were obtained when cassava was irrigated every 8 days.

When reporting about irrigation, many researchers do not include enough information about soil type (moisture holding capacity) and climatic conditions, which are extremely important for decisions on whether a crop needs irrigation. In addition, the spacing, age, and vigour of the crop influence its needs.

Celis and Toro (1974a, b) indicated that lack of moisture causes serious losses in sprouting if the deficiency occurs during the first 20 days after planting. A severe drought when plants are very small may also cause plant losses. Consequently, the soil should be irrigated to field capacity when moisture is lacking. If there has been no rain for at least 4 days during planting and irrigation is not feasible, planting should be suspended until the next rain.

Pruning

Some methods of planting such as horizontal often result in three to five main sprouts that compete for space during the development of the cassava plant. For this reason, EMBRAPA (1975) for Amazonas, Brazil, recommended thinning sprouts to two per plant after sprouting of the stakes. This is normally done during the first weeding. Santos et al. (1972) stated that later pruning should not be done until the plants are a year old and then only when propagation material is needed or when the crop is attacked by other pests. In the latter case the pruned portions should be removed from the field and burned.

EMBRAPA/EMBRATER (1976) also recommended that for the state of Ceara, Brazil, pruning be done only for problems with pests or for propagation material. In the latter case, branches should only be pruned when the crop is dormant, which in this area is January–March.

Some Colombian farmers commonly remove the suckers, vigorous shoots that arise from the bases of the main stem usually after the basic plant structure has been well established. CIAT (1976) reported that suckers are useful to a plant only at low populations or with low vigour types; otherwise, they are inefficient and reduce yields. For this reason removing the suckers is probably a beneficial practice for some cultivars.

Enyi (1972) reported from Africa that single-shoot plants outyielded multishoot plants, the difference increasing with a decrease in spacing distance. The single-shoot system and certain spacings were recommended for specific cultivars. The removal of the extra shoots should be carried out soon after the plant's emergence. Chan (1970), however, reported that pruning the plant to one stem led to a reduction in the root yield, and Shanmugham and Srinivasan (1973), studying the effect of single shoots and multishoots, found that two shoots outyielded the single-shoot and multishoot plants.

In 1977, Correa recommended against pruning until harvest because of the possibility of spreading bacterial blight and virus diseases. It was found that pruning at 6, 9, and 12 months limited yield by 43, 44, and 53% respectively. There was no effect after 15 months. Lozano et al. (1978) found that pruning plants about 25 cm above ground and leaving the roots in the ground for up to 20 days before harvesting actually decreased postharvest root deterioration from 100% to less than 20% depending on the variety. Tan and Bertrand (1972) stated that, as soon as stakes have sprouted new stems, many growers choose to maintain one stem per plant, whereas others prefer two stems per plant. Whether one chooses the single- or double-shoot system is of special importance in areas where cassava leaves are harvested periodically for human and livestock consumption; however, the choice at present is based more on tradition than on scientific research.

Crop Rotation

Usually cassava is the last crop to be planted in a rotation program because of its exceptional ability to extract nutrients from the soil. Cassava extracts more nutrients from the soil than most other tropical crops at least in respect to phosphorus, potassium, and magnesium, (Howeler 1978). For this reason it is often advisable to leave land fallow or to rotate crops following the second or third consecutive cassava harvest, especially in medium to poor soils. If another crop must be planted immediately after cassava, fertilization with chemicals or manure should be considered.

Okigbo (1978) reported that in fields left fallow in East Africa, several different crops are commonly planted such as maize and beans, sweet potatoes, bananas, yams, or sugarcane, which are in turn followed by cassava. Albuquerque (1969) indicated that in poor soils in Brazil the most recommended rotation for cassava is with legumes especially *Cannavalia ensiforme*, *Cajanus indicus*, and *Arachis hypogaea*. Sasidhar and Sadanandan (1976) found that growing cassava after cowpeas on a red loam acid soil (pH 5.8) was more profitable than any other sequences involving cassava. Normanha (1971) noted that crop rotation is very important, cassava being a good crop to follow such crops as cotton, maize, rice, sorghum, peanuts, soybeans, and beans. Rotation is especially advisable following years of cotton cultivation because of the expected phosphate residues in the soil. Control of cotton insects should also benefit cassava as would any crop residues

(O.M.) in the soil. Correa (1977c) recommended beginning a rotation program as soon as cassava yields begin to decline and using soybeans or any legume normally grown in the area. In São Paulo state, good results were obtained in cases where the legume *Stizolobium* sp. was planted, cut, and plowed under as a green manure following every two cycles of cassava. Castro (1979) recommended, as a soil management practice, rotation of crops as a means to maintain soil fertility and to avoid the incidence of pest problems. Lozano and Terry (1978) recommended rotating cassava with corn or sorghum or fallowing land for 6 months when root rot levels are higher than 3% due to *Phytophthora drechsleri*. This practice should reduce the inoculum population enough so that cassava can be grown again.

Although cassava is noted for its ability to yield well on acid, infertile soils, it extracts 100 kg of K_2O for each 25 t of roots. Grown continuously without adequate fertilization, the cassava may exhaust the potassium reserves in the soil (Howeler 1978).

Harvesting

Harvesting is extremely laborious when performed manually; it is also costly. Diaz et al. (1974) reported that harvesting in Colombia represents more than 30% of the production costs. The manual methods that are usually employed are rudimentary and inefficient, although Toro and Jaramillo (1974) have described several manual and semimechanical devices that facilitate harvesting, improve efficiency, and thus reduce costs and fatigue. In 1970, Beeny indicated that vibration would facilitate cassava harvesting, and according to Briceño and Larson (1972), vibration combined with pulling or lifting is an efficient means of harvesting. When pulling alone is used, the stem may break and the roots remain buried. Briceño and Larson developed a blade lifter that is attached to the tractor by a three-point hitch. The tool requires 80 h.p. at the power take-off and gives a field capacity of 0.29 ha/day. Bates (1957) suggested that a modified potato harvester could do the job in cassava.

Hossne (1971) indicated that a couple of resistant and modified bands inclined like those used for sugar beets could be used for harvesting. Leihner (1978) evaluated two cassava harvesting machines in a friable clay-loam ultisol at CIAT-Quilachao experiment station using three different varieties at 5000, 10 000, and 20 000 plants/ha planted vertically on the flat. Plots of varieties MMex-11, CMC-84, MCol-22, which are classified as difficult, intermediate, and easy for manual harvesting, were harvested mechanically and by hand. The machines used were a Richter harvester manufactured by Richter Engineering Ltd, Boonah, Australia, and a CIAT lifter. The results indicated that both mechanical methods left fewer roots in the soil than did manual harvesting of the difficult-to-harvest variety, and the difference in performance of the two machines was small. Both harvesters cut down time and effort involved. Kemp (1978) with the same machines in the same field with the same varieties found that both harvesters proved to be positive alternatives to the drudgery of manual harvesting. For mechanical harvesting, Cock et al. (1978) recommended a compact or clumped type of rooting that can be obtained by selection of the right variety and by use of stakes that have been cut straight across and planted vertically on ridges.

Wijewardene and Garman (personal communication) reported the performance of four mechanical cassava harvesters working in a wet clay soil with 10 000 plants/ha planted on the flat. Cassava tops were manually cut and removed before the trial. The results were: Ransomes, a European root-crops harvester with a fixed blade and chain elevator, performed well with good separation of dirt and roots with a rate of operation of 4.5 hours/ha; A.P.I. operating on the vibrating blade principle with oscillatory elevator was a failure in the clay soil, although it had worked satisfactorily in dry, light soils of Ghana; Alpha-Record, an oscillatory blade and lifter design, also demonstrated the unsuitability of oscillating mechanisms on wet clay soils; and CIAT, a simple blade with lifter, designed and developed at CIAT by agricultural engineer, Alfonso Diaz, and built at IITA, performed the best of all. The soil and cassava roots flowed well over the blade, the lifting mechanism leaving the roots well loosened and exposed (about 50% out of the soil). The rate of operation was 3.5 hours/ha.

This trial was valuable in that it pointed out the right way to go for fully mechanized harvesting: a simple lifting blade, like the CIAT tool, 2 m wide for two rows, followed by a two-stage, endless-belt elevator to separate soil and dirt and deposit the roots into a trailer traveling alongside.

With cassava production increasing, many machinery manufacturers are interested in developing new harvesters; for instance, G.M.D. of Reims, France, has released a cassava diggertype mounted for linkage on the hydraulic lift of the tractor.

No matter what harvesting method is used, some general considerations are applicable: if planting is done on ridges or beds, harvesting tends to be easier than on flat ground; in loose or sandy soils, harvesting is easier than in clay or heavy soils; and in any type of soil, harvesting is easier when the soil is wet than when it is dry.

Conclusions

One cannot generalize about cultural practices for growing cassava in any country, although there are some agronomic practices that have proved to be effective everywhere. Each production area has soil and climatic factors that are specific to the locality, and the responses of individual cassava varieties differ from one place to another. Whenever an appropriate technology is needed for a specific cassava-growing region, it must be developed by national research organizations. In many cases, little adjustments to recommended technological packages are enough for good cassava production.

IITA and CIAT have been engaged in cassava research for the last decade. Working in a multidisciplinary team approach, they have obtained good results from applied research.

Using improved cassava technology based on low inputs, CIAT, after 5 years of regional trials with consistent results, has indicated that it is possible for farmers to double cassava yields with their own local varieties by following the recommended technological package. The package comprises two parts: one for areas where cassava is traditionally grown and the other for areas of subutilized ultisols and oxisols, which represent about 1.76 billion hectares of the world.

Technology for traditional cassava-growing areas: (1) good soil preparation; (2) selection and treatment of planting material (Lozano et al. 1977); (3) planting at the beginning of the rainy season; (4) planting 20 cm stakes in vertical position with buds facing up; (5) planting on ridges where soils are heavy and rainfall is more than 1200 mm/year (Lozano and Terry 1978); and (6) planting 10 000 stakes per hectare unless local research indicates a different population.

Technology for ultisols and oxisols: (1) all steps described for traditional cassava-growing areas and (2) fertilization (Table 2). The plan in Table 2 was derived from 9 years research at ICA-CIAT, Carimagua station. The plan contemplates

Table 2. Fertilization plan for continuous cassava production in ultisols and oxisols (Howeler, personal communication 1979).

	Dosage (kg/ha)[a]			
Fertilizer	1st year	2nd year	3rd year	4th[b] year
10-20-20	1000	750	500	1000
Dolomitic limestone	1000	–	–	1000
Sulfur	10	10	10	10
Zinc	5	5	5	5

[a]When cassava is planted only 1 year, fertilizer should be split accordingly.

[b]After the 3rd year, the plant starts over again.

planting cassava in the same field year after year. Dolomitic limestone must be incorporated, and the other products can be applied in bands side by side at the time of planting. For the treatment of stakes, 20 g of zinc sulfate per litre of water should be added to the fungicide and the stakes immersed in the mixture for 15 minutes. For the Colombian oxisols, planting time should be between 15 September and 20 October so that the incidence of pests and diseases is minimized (Lozano and Terry 1978).

To take more advantage of future information on cassava production research, investigators need detailed descriptions of soil, climate, the objectives of research, materials and methods used, data collected, and statistical evaluation. With these factors, they can extrapolate results.

Because the cassava dry matter content is highly correlated with its starch content and because starch is the most important product of cassava anyway, it is of great importance to indicate this information. Also, researchers must know the number of days to harvest to make real comparisons on yield because the dry matter accumulation per hectare per day is one of the best indicators of the yield potential of any variety. Experiments must be repeated at least 3 years in the same location before conclusive results and recommendations can be arrived at.

More research is needed in the area of cassava forage production and utilization because the cassava tops represent 40–50% of the total plant. More is needed also in the area of storage and production of cassava stakes, especially in areas of extreme climatic conditions and severe pest and disease stress.

Finally, one may conclude with Normanha (1975) that the most important cultural practices for cassava root production are selection of healthy and mature stakes; planting time; and good weed control. These simple practices can be considered universal in cassava production because they apply everywhere.

Cassava Planting Material: Management Practices for Production

Abelardo Castro M.[1]

Good quality planting material is the basis for high root yield. Cassava is a traditional crop that uses few improved cultural production practices and technologies. Research data have identified major biotic and abiotic problems and defined practices that avoid, reduce, or eliminate them. This paper suggests an integrated on-the-farm plot management system for the production of high-quality planting material and high root yields.

Introduction

As the area and intensity of cassava cultivation continues to increase, disease and pest attacks will also increase in their intensity. The common belief that cassava does not suffer from pests and diseases does not hold true any longer because more than a hundred insect and mite species have been recorded and about 30 cassava diseases induced by viruses and virus-like causal agents, mycoplasma, bacteria, and fungi have been reported (Lozano and Booth 1974). Some pests and diseases can induce heavy losses or can even cause complete crop failure, and others do not at present cause economic losses. The recent introduction and consequent outbreak of the mite *Mononychellus tanajoa* in West Africa has caused serious crop losses. Nevertheless, cassava is more tolerant of disease and pest attacks than are many other crops because of a lack of critical periods in yield formation (Cock 1978). Cassava yield must be evaluated according to three criteria: the roots, which are the edible or salable product; the stems, which constitute the propagating material; and the destination of the crop, because if no utilization is provided for the roots or stems there is no reason to cultivate the crop. In this paper the production of good cassava planting material, as it relates to diseases, pests, soil fertility, and general management, is discussed.

[1]Agronomist, Cassava Program, CIAT, Cali, Colombia.

Cassava Cultivation

Cassava, being a traditional crop, is grown according to long-standing practices, although the introduction of new technologies based on existing practices could significantly increase yields. In fact, the results of 5 years of regional trials at eight locations in Colombia conducted by CIAT have shown threefold increments in the yields of local varieties by the use of selected and treated planting material, adequate soil preparation, optimum planting density, and timely weed control (CIAT 1979). Yield can be increased further by the introduction of new disease- and pest-free cultivars if they have been adapted to the ecosystem, and optimum yields can be obtained through the introduction of new hybrids with resistance to the negative production factors of a given ecosystem.

In any vegetatively propagated crop, good planting material (stakes) is necessary for high yields. In cassava, poor sprouting or low-vigour stands may drastically reduce yields and the production of propagation material. Cassava stakes have the ability to sprout even under severe stress conditions, but sprouting does not necessarily imply high root yield. At present, low yields at the farm level are considered to be a characteristic of this crop. Consequently, farmers often underestimate the need for adequate selection of planting material, and this job is performed by labourers who have not received specific training in this aspect. Thus, in most cassava plantations, plant stand is lower than the number of stakes planted originally, and there is high variability in vigour from one plant to another. Although edaphic and climatic factors may account for some losses, the use of high-quality, clean stakes, as described elsewhere (Lozano et al. 1977; Nestel 1976), will generally reduce the relative frequency and intensity of losses. Unfortunately, cassava growers may not be willing to adopt practices that might increase production costs (the stakes would have to be purchased).

Sources of Planting Material

Unlike seeds of grain crops, cassava stakes are not commonly sold, and the farmers usually produce their own planting material. To supply stakes continually to satisfy their planting requirements, they must often introduce stakes from neighbouring regions because the stakes cannot be stored for an extended time. As the need for and interest in introducing or increasing the availability of a cultivar with desirable characteristics expands, farmers, institutions, and governments are increasingly exchanging cassava planting material. Expansion of cassava cultivation, production, and productivity is being threatened by a lack of knowledge or an underestimation of the many disease and pest problems that may be introduced through shipment of vegetative planting material. Lack of quarantine regulations also increases the danger of pest introduction into new regions or countries.

Quality of Planting Material

Both abiotic and biotic factors affect cassava crop production. Abiotic factors are determined by climatic and soil conditions; they set the potential production of the crop. Usually it is not economic to alter these factors, but a knowledge of the prevalent conditions will be useful in managing the crop for optimum yields. The climatic factors are primarily temperature and rainfall. In general, mean annual temperatures below 22 °C imply a growth period of more than 12 months, whereas temperature fluctuations for a 24-h period determine disease incidence. Total rainfall and its distribution also affects disease and pest incidence and, hence, yield potential. In general, two rainy periods alternated with dry seasons reduce pathologic and pest problems. The soil factors limiting cassava productivity are low pH, high aluminum concentration, low fertility, low organic matter content, and textures of either clay or sand.

Biotic factors, both diseases and pests, can limit cassava productivity to various degrees, and the variety of the cassava also reduces yields if not adapted to the environment. In addition, fungi, bacteria, viruses, virus-like and mycoplasma diseases can localize in roots, causing rotting; foliage and green stems, reducing photosynthesis and affecting total plant vigour; and in the propagative material. In this paper we are mostly interested in the diseases and pests that can be found in the stakes (because they affect sprouting or yield when they are used as vegetative reproductive material) and in those that attack planting material while in storage.

Cassava pests and diseases have both been discussed and their control measures recommended elsewhere (Bellotti 1978; Bellotti and van Schoonhoven 1978b; Bock et al. 1976; Lozano 1977, 1978b; Lozano and Booth 1974). Their control must be approached from two different angles. One is through research; the other is through farming practices. Basically, in-depth knowledge is sought on the biology, interrelationships of the problem with the crop, bases for biological control, rate of spread of the causal agents, vector efficiency, crop loss, identification of resistance genes, and the creation, through breeding, of tolerant or resistant cultivars. However, this is a long-term process. In the meantime, with the knowledge available, farmers have at their disposal technological and cultural practices (Castro 1979) that control, reduce, or possibly eliminate the problem from a field. When applied, these practices have been shown to increase yields immediately.

On-the-Farm Plot Management

Research efforts and findings must be channeled into extension activities so that they reach farmers and ensure good planting material. The first responsibility of researchers is to define the status of cassava diseases as completely as possible on a regional or country level. They can gain some insights from past workshops and symposiums on diseases, causal agents and vectors (Brekelbaum et al. 1978; IITA 1972; Maraite and Meyer 1979; Pires de Mattos et al. 1979). It is known, for example, that African mosaic disease (AMD) and brown streak virus (BSV) are restricted to Africa and probably India, as common mosaic virus disease (CMVD), leaf vein mosaic (LVM), and latent viruses (LV) are restricted to tropical America (Lozano 1978b). If one considers distribution, incidence, and losses, AMD is the most important disease of cassava because it can cause losses of more than 50% or as little as only 2% (Bock and Guthrie 1978), depending on the conditions for control of the whitefly vector (*Bemisia* spp.). The low rate of spread of mosaic into mosaic-free plots (2% in 14 months) and also within plots (13%) indicates that whiteflies are comparatively inefficient vectors and that man is the principal vector in his indiscriminate use of infected stakes as propagation material (Bock and Guthrie 1978); indeed he is also the only known vector of the CMVD in the Americas. Consequently, these diseases can be controlled easily by the use of healthy planting material (Costa 1971). Once the presence of the disease is determined in a region or country, clean-up can be achieved by meristem culture carried out by the national agencies, as described elsewhere (Kartha and Gamborg 1979), and production of disease-free material can be done in multiplication units outside the infected area. A second responsibility of researchers in conjunction with extensionists is to develop field diagnosis techniques that can be translated into educational programs for cassava growers, who need to become fully aware of the economic importance of the disease. This will be mainly an extension education responsibility. Only when farmers achieve a certain level of agricultural education, will they be willing to apply the recommended control measures: roguing diseased plants, obtaining disease-free stakes from local institutions, and planting them — whether they be local or introduced cultivars — in isolated plots to increase the amount of clean planting material. In other words, a prerequisite is that the farmers believe in the benefit of what they are doing.

The following recommendations, if implemented, will help to keep cassava crops disease- and pest-free and will provide more and better planting material.

(1) Plot location. The multiplication plot should be in an isolated but accessible area of the farm because continuous inspections of the crop should be carried out. Whenever possible, fertile, medium-textured, and well-drained soils should be selected. If drainage is poor, it must be improved before planting. If rainfall is higher than 1200 mm a year, planting on ridges is recommended. The plot should be located close to irrigation ditches that can supplement deficient rainfall. The cropping history of the plot must be known, and, if possible, either the most recent crop should have been Gramineae or the plot should have been left fallow to break biological cycles of pests and diseases.

(2) Soil preparation. The plot should be deeply plowed, disked, and ridged, if necessary, and the improvement of drainage and irrigation facilities should be considered. Soil chemical analyses must be made and fertilizer applied accordingly. Fertilization of cassava may not always increase root yields, but it does increase aboveground growth as measured by harvest index (CIAT 1979). Recent research data (R. Howeler, CIAT, personal communication) and field observations indicate that root yields are higher from stakes originating from well-fertilized soils than from those coming from low-fertility soils. In relation to diseases, NPK fertilization of cassava induces resistance to cassava bacterial blight (Arene and Odurukwe 1978). Further studies are recommended so that induced resistance to other diseases and pests can be evaluated.

(3) Varietal selection. Farmers have a choice when multiplying a cultivar: they can clean their own traditional cultivar or they can multiply one that is introduced. To choose the best alternative, they should consult with extension agents in conjunction with researchers to ensure the new cultivar has been adapted to the local ecosystem.

(a) Adapted cultivars are those that produce stable yields throughout the years. A cultivar not adapted to the ecosystem will yield few or no stakes and root yield will be low.

(b) The multiclonal system consists of the mixed planting of several cultivars and is a system frequently used by traditional, small cassava growers. The basic principle is based on the different degrees of tolerance and resistance to various pest and disease problems, such that the rate of spread of the causal agent of the problem is delayed when moving from one plant to another from a different cultivar. The use of this system on a commercial level is something yet to be studied. Basically, the agronomic characteristics of the multiclonal system must be similar, but they must differ in their resistance or tolerance to the various pest and disease problems.

(4) Spatial arrangement. Results indicate that there is an optimum planting density for different cultivars in different ecosystems (CIAT 1979) and also that a square or rectangular planting pattern does not significantly affect root yields if optimum planting density is used.

Strip-cropping research being carried out at present by CIAT and double-row cropping as reported by Pires de Mattos et al. (1979) may be suggested for optimal aboveground growth. The uncultivated strips allow for easier and more efficient visual inspections of the field; for the application of chemicals, protectants, and fertilization; and also for the ease of management of the harvested stakes within the cultivated strips. Planting density may be altered according to plant type so that stake number and root yield are optimized.

(5) Postcultivation management of the plot. Cultivators must give emphasis to inspecting fields periodically; roguing and burning diseased plants; and controlling weeds to have vigorous cassava plants. If possible, the field should be supplemented with irrigation when rainfall is deficient. There are several pests that feed on stems and leaves (*Erinnyis ello, Atta* sp., *Acromyrmex* sp., *Zonocerus* sp., *Vaginulus plebeius*) for which there is no source of varietal resistance (the field must be kept under visual inspection and sprayed with protective insecticides or attractants applied as soon as any of these pests appear). Insecticides like Aldrin and Carbofuran should be applied to the soil and around the planted stake to control attacks of larvae of Scarabaeidae, Cerambycidae, and *Coptotermes*, which attack the stakes and cause the death of young plants.

Stake Selection and Handling

The basic considerations for stake selection and handling are described elsewhere (Lozano and Terry 1977; Lozano et al. 1977). The most important factor is the visual selection of stems from apparently healthy plants. The plantation should not be left after the crop reaches maturity because buds lose their viability, the stems become too lignified, decreasing sprouting, and the presence of undetected pests and diseases is more likely.

The machinery, machetes, equipment, and labourers should be carefully disinfected before entering a new field, and the machetes should be disinfected with detergent and water between plants. The discarded vegetative material must be removed from the plot and burned to avoid substratum for pest and disease development. The handling of either short stakes or stems should be done as carefully as possible so that they are not damaged. For the same reason, it is recommended that cardboard or wooden boxes be used during transport and storage. Stake treatment is recommended by Lozano et al. (1977) for the production of planting material. If storage of more than a week is required before planting, chemical treatment is a must.

Storage of Planting Material

Much more research is needed on the storage of planting material, as the material often has to be stored for extended periods (up to 5 months) due to flooding, drought, or cold weather. During flooded conditions, the stakes are stored in floating houses, and in cold places where frost occurs, they have to be kept in a vertical position in trench silos. Large plantations cannot use such methods because of their large volumes. Research in progress at CIAT (1980) suggests that 1-m stems, treated with BCM and Captan (Bavistin and Orthocide) at 3000 ppm each before storage, given the standard dip treatment, and stored up to 90 days in shady open-air conditions, can produce a stand of about 95% of what can be produced at harvest by freshly cut stakes, but root yield is reduced by 32% (see Fig. 1, page 36). Further studies under flooded, drier, and colder climatic conditions are needed.

Thanks are expressed to Dr J. Carlos Lozano for his suggestions and reviewing of the paper.

Influence of Period and Conditions of Storage on Growth and Yield of Cassava

Antonio M. Sales Andrade and Dietrich E. Leihner[1]

Cassava planting often takes place during the rainy season, but harvesting is carried out during the dry season, thus there may be considerable periods of time between harvest and subsequent planting. As a result, storage of planting material for up to several months is necessary.

A great number of storage methods are used to preserve the stakes and protect them against physical damage, dehydration, and extreme temperatures. Chemical treatment is highly efficient in preventing pathogenic infestation, which is an important factor causing germination losses. In adequate storage conditions, chemically treated stakes can be preserved for 6 months under CIAT's conditions. Although there may be no losses in final stand, vigour of planting material is reduced and the number of thick roots tends to decrease. This translates into lower yields coming from stored stakes.

Practices that could reduce the effect of storage on the initial vigour and formation of thick roots could contribute to minimizing yield losses.

Cassava in Brazil is usually harvested in the so-called dormant periods between two rainy seasons because the product reaches a better commercial quality, with a maximum of root production and starch content (Conceição 1976; Normanha and Pereira 1964). When stakes are harvested during this season and are kept for the following planting, storage for up to 6 or 7 months may become necessary, as is the case in the northeastern part of Brazil (Correa and Vieira Neto 1978).

Cassava propagation material is susceptible to adverse climatic conditions and to pests and diseases. Thus, when exposed to the sun after cutting, it can loose viability in a short time due to dehydration. But excessive moisture may cause bud sprouting. Pathogens and pests are also common causes for bad sprouting after planting. Better sprouting is obtained with stakes harvested shortly before planting if compared to stored stakes (Correa 1970, 1977a, b; Silva 1970). Besides, there are varietal differences in the sprouting vigour of stakes, which are emphasized with extension of the storage period (CIAT 1977; Lozano et al. 1977).

[1]Monitor of the Cassava Project, EPAMIG and Specialist in Cassava Cultural Practices, CIAT, respectively.

Storage Period and Conditions

When storage is necessary, it is advisable to protect stakes against external agents and dehydration by using chemical products. Another possibility would be to inhibit early sprouting of buds and stimulate them when necessary. Theoretically this is possible and studies are being done in this field using hormones (CIAT 1978). However, hormone use is complex because slight mistakes in dosages can produce contrary effects, making application under farm conditions difficult.

The literature shows discrepancies in relation to the maximum possible period of stake storage. If no fixed period of time is given, expressions like "reasonable period," "several months," or "some time" are mentioned. Lozano et al. (1977) observed good sprouting after a storage period of 30 days, reference has also been made to 8 weeks (Krochmal 1969), to periods longer than 30 days (EMBRAPA 1976), and to a possible period of from 3 to 5 months (Mendes 1949).

The different opinions among researchers in relation to adequate storage conditions are due, at least partially, to the different environments in which they work, as well as to methodological and varietal differences. According to

Kiernowski (1950) cassava varieties have different storage performance depending on the conservation method used. Lozano et al. (1977) mentioned that there are sprouting differences between varieties that are stressed by extension of the storage period.

However, in spite of the different points of view, some aspects are common to all investigations.

(1) Stake storage. Storage should be avoided, if possible. Silva (1970) and Correa and Vieira Neto (1978) mention a trial in which a high percentage of sprouting was obtained with stakes planted shortly after harvest (100%) as compared to stakes kept vertically under tree shade (70%), in the field in a horizontal position (50%), under partial shade (80%), and in a cold room used for seed potatoes (20%).

(2) Stake position and storage environment. Horizontal and vertical positions are equally recommended and produce good results when storage is carried out in cool and shady environments avoiding direct sun, hot or cold winds, and dehydration.

(3) Position. When stakes are stored vertically, the buds should be facing up to obtain better sprouting.

(4) Stake length. Long stakes are better preserved than short ones (Castellar and Mogollón 1972; CIAT 1973, 1974).

(5) Stake quality. Stakes should have the right maturity and come from healthy cassava plantations. Material attacked by pathogens and/or pests should be avoided. In areas subject to frosts, stakes should not be stored above ground under field conditions.

Lozano et al. (1977) suggest the use of varieties tolerant to storage because they usually have a better sprouting potential. Stephens (1965) recommends stakes with the right maturity. These should not be wet when stored nor should they be exposed later to humidity.

Chemical Treatment

Stake spraying with a solution of Bordeaux mixture at 0.25% (Normanha 1946) or at 0.50% (Normanha and Pereira 1950) before storage prevents fungal attack. Mercury products used before storage also help to obtain good conservation (Viegas 1976). For CIAT (1974), stake treatment with the commercial product CIPC delayed bud sprouting 4 weeks, and according to CIAT (1979) the use of sodium alginate prevents dehydration during storage.

Lozano et al. (1977) mentioned that fungicide treatment before storage results in more than 90% sprouting after a month and a yield increase of more than 25%. A mixture of fungicide, insecticide, and/or miticide should be used. Among other products, a mixture of Orthocide and Bavistin (BCM and Captan) at a rate of 3000 ppm each is recommended. The advantages are their disinfective and protective action, the increase of conservation time, and the speed of sprouting and rooting.

In a 4-week conservation test using a variety with high sprouting potential (M Col 946), and another with low potential (M Col 803), and previous stake treatment with a mixture of BCM and Captam, the following yields were obtained: M Col 946 treated 28.0 t/ha, untreated 18.0 t/ha; M Col 803 treated 25 t/ha, untreated 0 t/ha (CIAT 1977).

Yield Trials

To evaluate this technology in longer storage periods under different conditions, a trial was carried out using planting material of the good sprouting variety CMC 76. Storage periods were 0, 30, 60, and 90 days. Storage conditions were a dry room on a wooden base (horizontally) or placed on the ground (vertically, with buds facing up) under a bamboo canopy, and covered with plastic in earth silos. The material was previously immersed in a solution of BCM and Captam (Bavistin and Othoxide) at 3000 ppm each.

When storage periods ended, the 1-m long bars were cut into 20 cm stakes and treated with a mixture of fungicides, insecticides, and micronutrients, in a preplanting treatment, and were ridge planted at 1.0 × 1.0 m. The field was previously irrigated to ensure good humidity conditions.

Sprouting

The final sprouting percentage as well as the sprouting rate (number of plants/day/plot) was determined. In adequate storage conditions (dry room or bamboo shade), the sprouting rate was greater in stored material than in fresh material, independent of storage period. Even with inadequate storage conditions (earth silos, 1.0 m or 20 cm stakes) the sprouting rate with 30 days of storage was higher than the rate obtained with fresh material.

The final sprouting percentage was almost not affected by storage duration under adequate

Table 1. Cassava fresh root yield as influenced by condition and time of storage of planting material (CIAT 1979).

Condition of storage	Time of storage (days)	Stand at harvest (%)	Root yield (t/ha)
Dry room, 1 m stake, vertical	0	100	35.5
	30	100	29.7
	60	98	26.9
	90	98	24.0
Open air, shade, wooden base, 1 m stake, horizontal	0	100	35.5
	30	100	24.5
	60	100	24.0
	90	94	25.5
Open air, shade, 1 m stake, vertical, on soil	0	100	35.5
	30	100	31.9
	60	100	27.8
	90	96	23.9
Earth silo, 1 m stake, plastic wrap, horizontal	0	100	35.5
	30	73	20.3
	60	65	19.6
	90	0	0.0
Earth silo, 20 cm stake, plastic wrap, horizontal	0	100	35.5
	30	96	31.5
	60	79	21.8
	90	0	0.0
C.V.%		8.7	16.0
SD		7.26	3.9

Table 2. Effect of storage duration of planting material on root characteristics of cassava plants harvested 11 months after planting. Variety CMC-76, chemical treatment: BCM and Captan at a rate of 3000 ppm each. Means of five storage conditions (CIAT 1979).

Storage duration (days)	No. roots per plant	No. marketable roots per plant	Mean root length (cm)	Mean root perimeter (cm)
0	12.2a[a]	7.5a	26.3	19.8ab
30	11.5a	6.2ab	26.1a	19.3b
60	9.4b	5.1b	27.2a	21.1a
90	10.7ab	5.8b	26.7a	21.0a

[a]Figures followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test).

storage conditions, reaching 95–100% in all periods. On the other hand, the final sprouting percentage was drastically reduced with longer storage periods, when conditions were inadequate.

Cassava Yield

Both duration and condition of storage affected fresh root yield (Tables 1 and 2). Yield decreased as a consequence of longer periods of storage under any condition, but the decrease was more drastic under inadequate conservation conditions. The effect of length and storage conditions as well as their interaction were highly significant ($P = 0.001$). The significant interaction effect indicated that with longer storage periods, the conditions under which planting material is stored become more critical. Fresh root yields proved that the best storage condition in this trial was under a bamboo canopy with 1 m stakes stored vertically and buds facing up. Rooting and partial sprouting did not seriously affect conservation or establishment of the crop. On the other hand, stakes (1.0 m or 20 cm) wrapped in plastic and buried in silos of about 80 cm depth produced excessive humidity and suffered premature sprouting. This caused great reductions in sprouting after planting.

Under these conditions, the difference in yield due to different storage periods was explained by final stand percentage ($r^2 = 0.90^{***}$). In contrast, under adequate conditions (under bamboo canopy, on a wooden base, or on the soil) a great part of the variation of fresh root yield due to the different storage periods could not be explained by the final stand percentage ($r^2 = 0.42^{n.s.}$). This showed that besides plant population, other factors related to duration and condition of storage influenced root yields (Figure 1).

Size and Number of Roots

Plants from stored stakes produced less total and commercial roots per plant, than those originated from fresh material. Plants with less roots had a tendency to compensate for lower root numbers by increasing root size, however, this was not enough to balance production. The decrease in number of roots per plant was significant, and partially explains the reduction in yield ($r^2 = 0.80^{****}$) even under adequate storage conditions.

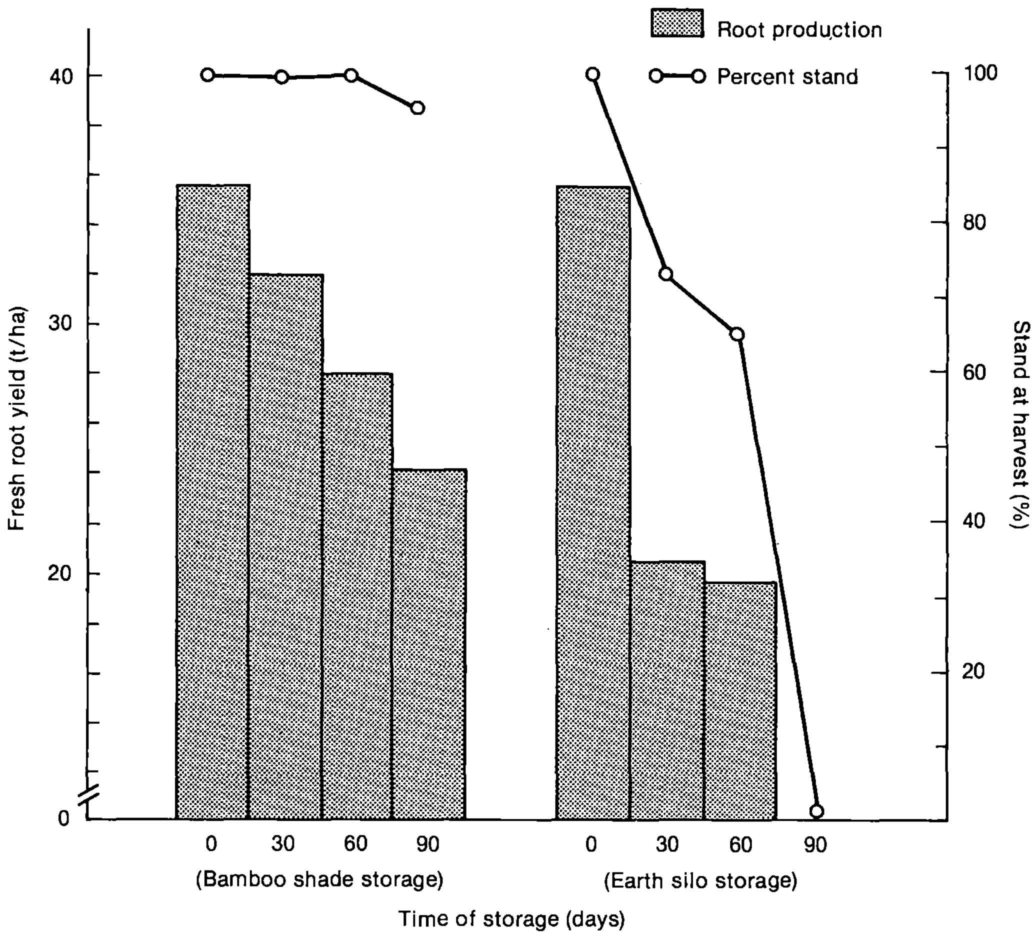

Fig. 1. Percent stand at harvest and cassava fresh root yield as influenced by time of storage under two different storage conditions at CIAT/Palmira, 1979.

Table 3. Effect of storage duration on growth parameters of stakes of variety CMC-40, kept under a bamboo canopy and treated with BCM and Captan (3000 ppm each).

Storage duration (days)	Sprouting 31 DAP[a] (%)	Sprouting rate (plants/day/plot)	Plant height 45 DAP (cm)	Leaf size 60 DAP (cm)	Avg. no. stems per plant 60 DAP	LTR[b] 76 DAP (%)
0	100a[c]	1.73a	26a	278ab	2.66a	23a
60	100a	1.83a	27a	282ab	2.73a	22a
120	100a	1.59ab	23b	253b	2.36b	28a
180	98b	1.40b	25ab	296a	2.23b	25a

[a]DAP = Days after planting.
[b]Light transmission ratio.
[c]Figures followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test).

Initial Growth and Storage Duration

In a recently planted trial with stakes stored for up to 180 days, the influence of storage duration on initial growth was studied in greater detail. Because the material was treated with fungicides and was adequately stored (under bamboo canopy, vertically, on the soil) no effect of the storage period on final sprouting percentage was observed, sprouting 1 month after planting being almost 100% even with 4 and 6 months of storage. However, there was a reaction in relation to other parameters (Table 3). A lower germination rate with storage periods above 60 days and shorter plants could be due to less vigour of the stored material. Also, smaller leaves (with the exception of 180 days storage) and the significant reduction of number of stems per plant as well as a higher light transmission ratio (LTR) may be an expression of this reduced vigour. It is interesting to note that there was no significant decrease in growth parameters with 60 days of storage.

Final harvest data should indicate how the reduced germination rate and slower initial growth, will affect the development of the root system and the formation of thick roots. Identification of factors that make plants from stored stakes less efficient in terms of early growth and thick root formation could allow the development of even better practices to preserve vigour of planting material and minimize yield losses.

Conclusions

The results and observations obtained up to the present are:

(1) The most important factor in cassava yield decrease due to stake storage is reduction of sprouting produced by pathogenic infestation or unfavourable environmental conditions during storage. Poor sprouting results in a deficient population at harvest.

(2) Under adequate storage conditions and chemical treatment, cassava stakes can be preserved for several months, keeping high sprouting percentages.

(3) In tropical climates, storage of planting material under tree shade, eliminates the need for special and expensive facilities.

(4) Storage conditions will be more critical the longer the duration of storage.

(5) When sprouting potential of stakes is preserved by chemical treatment and adequate storage conditions, yield reduction can no longer be explained by final stand percentage. In this case, it seems that other factors affecting top and root growth are responsible for yield variations.

(6) Identification of these factors will allow the identification of management practices for stored planting material, not only to ensure a high sprouting percentage but also to minimize yield losses.

Cassava Production and Planting Systems in Brazil

José Osmar Lorenzi,[1] Edgard Sant'Anna Normanha,[1] and Antonio José de Conceição[2]

Cassava is planted all over Brazil and involves multiple soil and climatic conditions as well as different socioeconomic aspects, especially at the rual level. Its roots fulfill diverse needs — a fact that enhances its cultivation. The agronomic practices in cassava cultivation differ according to the social and economic characteristics of the different regions, especially in respect to practices on plant population, fertilization, weed control, and stake size. Technology varies from primitive to highly sophisticated.

The northeastern part of the country, which accounts for 50% of the total cassava production, has the lowest yield average (6 t/ha). The national average is 14 t/ha, the southern part of the country being the region with the highest average.

Plant diseases constitute the main problem for cassava growers; in the central and southern states cassava bacterial blight is prevalent and in the north, superelongation. National cassava research is working to solve the production problems. In the short term, improved cultural practices are being developed and incorporated in technological packages for specific regions; in the long term new varieties are being created so that the phytosanitary problems can be overcome.

Cassava has been called the most typical Brazilian subsistence crop because of its relationship with Brazil's socioeconomic and historical development. At present, Brazil is interested in placing cassava among the national security crops — as a source of food, forages, industrial raw materials, and energy. Government institutions, at a commercial level, are studying cassava and are developing short-, medium-, and long-term research programs to gather scientific information to give technical assistance to cassava producers, to solve the problems in cultivation, and to develop technological processes for cassava products and subproducts. The federal government founded the Brazilian Agricultural Research Centre, EMBRAPA, linked to the Secretary of Agriculture and founded the National Research Center for Cassava and Fruit Crops (CNPMF) as a subsidiary, with headquarters in Cruz das Almas. The objective of these institutions is to carry out and coordinate research programs leading to yield increases, improvement in the quality of cassava byproducts, reduced production costs, and exploitation of underdeveloped areas for cassava and horticulture production. These objectives are defined in CNPMF's commodity research programs.

[1]Instituto Agrônomico do Estado de São Paulo, Campinas, Brazil.

[2]Departamento de Fitotecnia da Escola de Agronomia da Universidade Federal da Bahía, Brazil.

Northern Brazil

Northern Brazil contributes only 5.2% of the total national cassava production. The ecological area with the largest production in the region (about 70%) is the area of the Amazon Estuary, with an average production of 13 t/ha.

The socioeconomic aspects in this huge Brazilian region focus on the importance of cassava as a food crop. Per-capita consumption of cassava has been significant since colonial times, along with beans, sorghum, and rice. Cassava is an important crop in this area because it is easy to grow and is a well-liked, traditional food crop, often consumed as flour. At present, primitive exploitation methods and simple processing techniques are practiced in cassava flour factories.

More than 90% of the cassava is transformed into cassava meal, *pará* flour, and other typical foods such as *tucupí* and *tacacá*, etc. Although the region is not the site of large agroindustrial enterprises, it has considerable potential for increased cassava production.

Cassava Production Problems

The main problems are low soil fertility in many areas, excessive rainfall, low productivity of cultivars, pests and diseases, and primitive agricultural practices.

Northeastern Brazil

The northeast, comprising 1.52 million km² or one-fifth of the area of Brazil, includes nine federal states — Maranhao, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, and Bahía. As Brazil's largest cassava producer, it accounted in 1975 for 13.14 million tonnes of roots from a harvested area of 1.27 million hectares, which is almost 50% of the country's total production. Production has increased in the northeast, due greatly to an increase in the cultivated area, rather than to an increase in productivity.

Because of the high cost of fresh roots, among other factors, it is hoped that, in the long term, cassava can be used for a wider range of subproducts. For economic industrialization of cassava, the present supply of traditional products needs to be diversified through agroindustrial integration in which the industry will totally or partially produce its own raw material.

In future, production of cassava chips may assume importance in the northeastern part of Brazil because solar energy is abundant, and the technology for producing chips is simple. Furthermore, the high production potential of the region enhances the feasibility of establishing ethyl alcohol plants as a new agroindustrial activity.

The average person's consumption of cooking flour was estimated at 73.8 kg for the rural population and 32 kg for the urban population. The flour industry is limited primarily to small processors called "flour factories" that are usually located near cassava-growing areas. In some cities there are semi-industrial enterprises that use mechanical equipment for grinding the roots, hydraulic or air presses, spindles, and even mechanical ovens for toasting.

The state of Bahía, which is located in this region, has become the largest cassava producer in Brazil, contributing, in 1975, 25% of the total national production (5.109 million tonnes).

Cassava Production Problems

Serious problems plague cassava growth in this region — the main one being the amount and distribution of rainfall. It is common, after years of long summers, to see a commercial flow of baking flour from southern to northeastern states.

Primitive technical assistance and orientation have restrained the changing of traditional cutivation practices. Consequently, there is a low level of knowledge among producers, who continue to adopt obsolete production systems, including the use of low-yielding cultivars. Added to this problem are the insignificant numbers of industries, the existence of a large number of *minifundios* (small plots), and the production of other more profitable crops in areas near the coast where the *Tabuleiros Costeiros* are located. The lands bordering the coast have topographic and climatic conditions that make them particularly suitable for agricultural expansion; however, they will require fertilization. Cassava productivity is also reduced by plant pests and diseases, such as *mandarovás*, mites, ants, leaf spots, anthracnosis, and rust.

Southeastern Brazil

Southeastern Brazil is the third largest cassava producer in the country, contributing close to 15.5% of the total national production. It also has the best production systems and the greatest amount of product diversification. Flour, chip, sour starch, and baking flour industries, besides human consumption of fresh roots and the use of cassava for forages, use all the raw material that is produced.

Cassava Production Problems

Cultural problems in this region, in spite of the existence of research centres, are related to: (1) the presence of bacterial infection (which is a factor limiting production in many areas); (2) competition from more profitable crops such as sugarcane, soybeans, sorghum, wheat, and rice in most areas traditionally planted with cassava; (3) the low level of technology used by producers planting in low-fertility soils, without fertilization, mainly in Minas Gerais; (4) the planting of low-yielding cultivars; (5) the use of mountain areas, especially in the states of Rio de Janeiro and Spirito Santo; (6) bad rainfall distribution in Minas Gerais; (7) frosts in São Paulo; and (8) the high cost of land as well as the scarcity and high cost of labour in São Paulo.

Midwest Brazil

The Midwest is responsible for only 5.3% of total national production of cassava. Primarily comprising Cerrados, the area may expand cassava production because this crop can compete with other crops that demand higher fertility and water levels. Such expansion will probably depend on an increase in regional consumption of baking flour because the area is far from exporting ports and other large consumer centres.

Cassava Production Problems

In the Midwest, the problems are similar to those in other Brazilian regions, particularly the high prevalence of plant disease (bacterial blight), the use of low-yielding cultivars, low soil fertility, high levels of aluminum in the soil, and poor rainfall distribution, very often restricting the planting season to only 60 days each year.

Southern Brazil

The southern region contributes 27.9% of the total cassava production in Brazil. Starch, flour, chip, *polvillo aredo,* and pellet industries are located here, producing primarily for internal consumption and some export. Cassava is also used as a forage crop and to a limited extent for human consumption. The state of Paraná has the highest yields per hectare because of its fertile soils. However, cassava is of secondary economic importance because more profitable agricultural species are emphasized here. Nonetheless, Paraná is responsible for 7.1% of the total national production.

Cassava Production Problems

Problems in this region are practically the same as those in other Brazilian regions; the most significant are frost periods, bacterial blight, low-yielding cultivars, and poor storage of planting material. Other factors affecting productivity are the use of low-fertility soils, the lack of research, and the need for widespread use of better cultural practices.

Cassava Planting Systems in Brazil

The size of Brazil (8.511 million km^2), its complex climatic and soil conditions, the different socioeconomic levels in the rural areas, and the diverse use of products derived from cassava roots, (grown on a large and small scale) contribute to the heterogeneous nature of cassava planting and processing systems. As well, cassava is present throughout Brazil and is considered to be a permanent part of the culture.

The cassava-growing practices go from primitive — a piece of stem is planted in ground that has had no previous preparation by a farmer who has no idea of the nature, type, size, or quality of the plant — to very sophisticated, using machines and selected and treated stakes of genetically improved cultivars as recommended by research standards.

Several production systems (technological packages) were designed in 1976 with the implementation of EMBRAPA and the foundation of state research entities and were to be delivered to cassava growers throughout Brazil, who in turn could increase cassava productivity and raise their own socioeconomic level.

In the field, the main elements that determine the cassava production system start with soil preparation and include size and type of stake, stake treatment, stake's planting position, planting depth, spacing, planting season, fertilization, planting practices, and cultural treatments.

Soil Preparation

There are primarily four systems of soil preparation in Brazil:

(1) Simple cleaning of the area, whether cut or pruned with hand tools such as axes, picks, hoes, and scimitars followed by burning of residues, and planting in beds in the ground.

(2) Simple cleaning of the land, followed by hoeing, and planting in beds in the ground.

(3) Simple cleaning, with plowing and disking, using animal traction for plows and light disks.

(4) Cleaning, plowing, and disking using tractors.

The first three systems are used in small areas where cassava is grown as a subsistence crop. The third is used in areas dedicated to the production of raw materials for industries or to the production of fresh roots for human consumption. The fourth system is used in large-scale commercial plantings for industrial use or for sale as raw material.

Size and Type of Stake

(1) Stake size. For centuries, the Brazilian cassava grower has employed stakes that are no longer than 10–12 cm or have only a small number of buds. The reason may be that this

material, under favourable conditions, sprouts and produces roots that are satisfactory for the particular conditions of each farmer.

Research has shown that production per plant increases to a certain extent in relation to the size of the stakes; however when the stakes are being planted in rows, the sizes recommended are about 20 and 25 cm because a greater number of buds per stake is produced and, by implication, more stems and roots (Normanha and Pereira 1950; Conceição and Sampaio 1973b).

(2) Type and characteristics of stakes. Many farmers do not know the differences, sometimes many, that are caused by using different types and ages of stakes. Thus, the material used is very heterogeneous, as far as ripeness, diameter, number of buds, cleanliness, and cycle of the original plant that furnished the stems are concerned. In subsistence agriculture, the farmers are happy with any result.

Farmers exploiting small or large commercial areas are already aware, thanks to technology transfer, of the need to make critical selections of planting material. Thus, they usually plant ripe stakes that have been cut from the middle or lower part of healthy plants with a growth cycle of 10–12 months. In most cases, the leaves have already fallen from the middle or lower portion of the plant and because of the stem's thickness, the nutrient reserves are sufficient to provide better sprouting indices and plant survival. Some of these considerations are discussed by Mendes (1940).

(3) Stake treatment. Traditionally, the farmer rarely treats the stakes before planting. It seems that the few experiences in this regard did not give results that indicated the need for stake treatment. Current treatments are either to clean or disinfect propagating materials that have been contaminated by bacteria and fungi or to protect them against attack by these microorganisms.

In commercial plantations, immediately after the stakes have been cut, they are treated by immersion in fungicides, usually containing organic mercury, copper, or PCNB (nitrobenzene pentachloride).

Stake Planting

In general, stake planting in a horizontal position predominates when the planting is not done in beds or on ridges. The stakes are thrown into a low bed (a type of orifice produced by a hoe) or furrow, or pushed horizontally under a pile of earth.

In heavy soils, planting is done on ridges (earth piled in rows) or *matumbos* (elevation between furrows) so that the soil gets better aeration. In these cases, planting stakes are longer and are buried in a vertical or slanted position with the base down on top of the ridges or piles of earth.

Experimentally, stakes planted in a vertical or inclined position have produced better yield. However, this practice has not become widely used because planting in a horizontal position makes things easier during establishment and harvest (Normanha and Pereira 1950).

Planting Depth

Traditionally, the general trend has been to plant stakes superficially, that is covered by 5 cm of earth when planted horizontally. This practice is probably based on the fact of earlier sprouting of shoots during the rainy season, which gives the farmers the idea of a relationship with early harvesting. The farmers are anxious to see the plants. This gives them a sense of satisfaction and is a good indication of whether or not partial replanting will be required in small plots.

The farmers are correct in this procedure because planting at a depth of approximately 5 cm provides the best conditions for aeration and root formation (Brieger and Graner 1941).

Experimentation has shown, however, that horizontal planting is recommended at a slightly greater depth to improve the humidity conditions of stakes and to prevent solar burning and erosion due to heavy rains. The Economical Institute in Campinas (IAC) recommends planting at an approximate depth of 10 cm for horizontal stakes, not only to improve plant productivity but also to facilitate rooting and harvesting (Normanha and Pereira 1950).

When vertical or slanted stakes are planted on ridges, there is a tendency to plant the stakes so that their base is buried deeply.

Spacing

Distances between rows and between plants within the rows vary greatly and no pattern can be determined in subsistence cultivation. However, it is more important in plots where cassava is intercropped with common beans, climbing beans, upland rice, and sorghum. This is common in the northeast. The farmers program plantings and vary the distances between them to take into account the planting season, the harvest cycles, and the speed of growth and competition among crops.

In subsistence cassava plots, spacings vary from 1 × 0.50 m to 1.20 × 0.80 m, and often are 1.00 × 1.00 m, especially in the northeast. It is recommended, based on research, that spacings be 1.00 × 0.60 m for mechanized operations. For this reason, in commercial plantations, it is desirable to use 1.00 m × 0.60 m or 1.00 × 0.50 m spacings.

Planting Seasons

Planting is usually done at the beginning of the rainy season, which follows the summer season, when two essential conditions for sprouting and rooting of the planted stakes are found — humidity and heat.

Because of the size of Brazil, these conditions are not found in the same months in all regions. In the south, central, and southeast regions of the country, these conditions are found in the month of October; in the northeast, especially in the Tabuleiros coastal strips, planting takes place in April–May; and in the Amazon region, planting can practically take place year round.

Conceição (1978) published the results of planting-season trials, carried out in Cruz das Almas, Bahía, Brazil, that showed that the period between 15 April and 30 July was the best for planting. It is also possible to plant between 15 October and 15 December, taking advantage of rains from thunder storms. These results can be extrapolated to the coastal strips in the northeast, known as the best in the region for cassava production.

In southern and central Brazil, if there is delay in the planting season, plant diseases and pests increase. For instance, there is greater incidence of shoot fly (*Silba pendula*) and bacterial blight, as well as increased losses due to erosion, planting, initial cultivation difficulties, and the use of propagating material that has lost nutrients.

On the other hand, in the state of São Paulo, planting is feasible at the end of the rainy season (around May) or at the beginning of winter. This has certain advantages in that it usually means better conservation of stakes, fewer weeds, better control of shoot flies, and increased productivity (Normanha and Pereira 1948). Anticipated extension of planting may not be possible in Paraná, Santa Catalina, or Rio Grande do Sul due to the danger of frosts that kill plants during the early stages.

Fertilization

Currently, whether or not to fertilize is controversial in cassava plots because of the high costs of fertilizers and labour and the low price of the raw material that is produced. For example, in the northeast region, which contributes half of the country's total production, no fertilizer is used. In certain areas, however, fertilization with the residues from other crops (such as tobacco) is common, especially in Cruz das Almas and nearby cities.

Of the nutrients naturally available in Brazilian soils, phosphorus is the most scarce, followed by nitrogen. Although reaction to potassium is evident, no convincing response to this nutrient has been recorded in the coastal strips.

Under the edaphic conditions of São Paulo, the IAC carried out a series of surveys of mineral nutrients required by cassava and recommended fertilizers for each cassava region. In recent plantings in the Cerrado region, soils have been treated with dolomitic limestone (60 kg P_2O_5/ha), as simple superphosphate; 60 kg K_2O/ha, as KCl; and 50 kg N/ha in the form of ammonium sulfate after 40 days (applied by mulching).

Planting Practices

(1) Preparation or cutting of stakes. Preparation or cutting of stakes for planting is done manually with a variety of knives; the stem is held in one hand and cut with a light followed by a sharp strike at a point that gives the desired stake size.

The Agronomical Institute of Campinas in Brazil has for 10 years distributed a circular saw that is used mainly in large-scale plantings. This saw cuts the stakes quickly, saves labour, and produces a standard size planting material. Improvement of this simple tool started in 1964 through a private Mexican enterprise assisted by IAC's Technological Division in Campinas.

(2) Planting operation. Planting includes transportation of stakes to be planted; position of the stakes in the ground; planting depth; use of low beds, earth piles, *matumbos* (high and round beds), ridges, furrows, etc. Labourers carry stakes in bags on their backs and throw them onto beds or furrows, or bury them by the base in ridges or hills. The farmers use animals or machines to prepare furrows and ridges; however, hills and *matumbos* are prepared with a hoe. Stakes are completely covered with earth, unless they are buried vertically or slanted in which case they are usually longer, and the top portion is slightly above ground.

Planting has been done mechanically only in large areas used for industrial purposes. The first and oldest national cassava planter is Sans. Pulled by a tractor, it plows, fertilizes, plants, and covers the stakes in one single operation. It carries fertilizer and cut stakes. Two labourers put the stakes in cans placed in rotating drums, one for each of the furrows prepared by the machine.

Recently, a new planter appeared in Brazil that uses mechanical traction and eliminates manual cutting of the stakes. Like the Sans, it makes two furrows, but it takes entire stalks, automatically cuts and plants them in the furrows.

Cultural Treatments

Cultivation treatments include weeding, which is usually done with a hoe, usually 30 days after planting and subsequently when needed. A crop may be weeded three to four times during the first 12 months of the cycle. With an extension of the cycle from 15 to 18 months, one or two more weedings are needed before harvest.

An animal traction harvester has been recommended for the first two weedings in small areas, as long as the machine does not damage the aerial or underground parts of the plants. This machine is economic in areas that have been cleared of stumps or trunks and where weeding within rows is done with a hoe.

Preemergent herbicides have been used rarely, although some recently installed commercial plantations in Cerrados have been experimenting with them.

Pruning (separation of roots from plants at 9–12 months of the cycle) is traditionally practiced in certain areas; however research does not show any economic advantage to it. In fact, cassava pruning increases production costs, decreases starch formation, and increases fibre content, as the plant is forced to use up its hydrocarbons to rebuild the damaged aerial part. Pruning is only justified when planting material is needed, when the crop is infested with pests (in the case of bacterial infection, pruning increases the risk of spread of the inoculum), when the aerial portion is to be used as forage, or when the plants are threatened by frost. After pruning, a farmer should wait 4–6 months to harvest, so that the starch reserves in the roots are restored.

Cassava Planting Systems in Africa

H.C. Ezumah and B.N. Okigbo[1]

The target of research on cassava planting systems in Africa continues to be the small farmer who plants fewer than 2 ha, often at scattered locations, and who cultivates and weeds using hand tools. In Africa, cassava is generally grown in combination with other crops. As the last crop in an intensive cropping system that may involve 2–4 years of land utilization with crops such as vegetables, legumes, tree crops, etc. before cassava is finally introduced, cassava may be harvested from fields that have attained various stages of fallow. The planting practices, land preparation, and bush clearance methods are influenced by soil–water relations, consideration for which crop is intercropped with cassava, and the cropping history of the land.

Among the important factors resulting in low root yields in Africa are late planting (10% root yield reduction for every month's delay), untimely and inadequate weed control, and high incidence of diseases and pests. The enormous drudgery involved in land preparation and weed control, lack of a ready and sure market for the fresh roots, and transportation and processing problems combine to limit the scale of cassava-growing operations in Africa.

Scientific research aimed at confirming, modifying, or completely changing traditional cropping systems used by peasant farmers in tropical Africa is just beginning, but it has been widely recognized that these systems are based upon results of centuries of trial and error, given a particular socioeconomic environmental setting. A system once developed becomes more or less an integral part of the life system of the society and fulfills certain socioeconomic goals. With their limited resources, which must be shared among many other needs, subsistence farmers cultivating fewer than 2 hectares of land are usually reluctant to embark upon innovations that mean increased investment. Unless economically attractive, innovations that entail drastic changes in the farmers' way of life will probably fail to be adopted, even with intensive extension work.

A typical African cassava farmer grows the crops in mixtures. Methods of land preparation, crop combination, patterns of planting, population and spacing may vary with soil type and other ecological factors such as rainfall regimens. This paper reviews work on cultural practices used in cassava production in certain parts of Africa.

[1]International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Ecological Adaptation

Cassava is adapted to diverse environmental conditions and systems of cultivation. Neither is it limited to well-defined harvesting periods nor does it require special skills in production (Coursey and Haynes 1970). It is grown in areas ranging from humid (more than 2000 mm annual rainfall) to semi-arid (500–750 mm) in tropical Africa, between latitudes 15 °N and 15 °S. Though grown at altitudes ranging between 500 and 2000 m in East Africa, the most suitable range is 1500–1800 m (Okigbo 1978). It is grown mainly at altitudes less than 1000 m in West Africa (Onwueme 1978b). These facts suggest that varieties are adapted to different altitudinal ranges.

Cassava also grows in a range of soil types. Well-drained sandy loams, preferably rich in the essential nutrients, are required for high yields of good quality roots, although reasonable returns may be obtained from soils usually regarded as poor and infertile (Godfrey-Sam-Aggrey and Bundu 1972; Onwueme 1978b). Various levels of fertilization have been recommended for different areas, and critical nutrient levels have been reported. In general, improved, newly developed cultivars are more responsive to fertilization.

Local cassava varieties exist in adverse growing conditions, and their tolerance to high soil acidity may be related to generations of adaptation to the highly leached, acid soils common in tropical Africa (Edwards and Kang 1978; Rogers and Appan 1972). Indeed, Doku (1969) reported that 50% of the cassava grown in Ghana is in the forest zone where it is usually mixed with maize and cocoyam after a fallow of secondary forest has been cleared. Throughout Africa, cassava is grown in combination with another crop, which varies with ecological regions. Usually, cassava is the last crop in a rotation of crops that is continuous and covers 1–4 years, at which time the field is left fallow.

Land Preparation

Land preparation for cassava is basically the same as for most other arable crops. In the forest areas, it consists of bush clearing and some tillage. The amount of work required varies with the dominant vegetation and soil type. In the savanna, the field is simply set on fire before plot preparation, whereas in the forest zone the bush and some big trees must be cut and allowed to dry before being burned. The stumps may be removed. Preplanting cultivation is done with hand tools and entails ridging, mounding, or tillage on the plot. How a field is prepared (ridges, mounds, flat tilled or no tillage) depends upon soil type and drainage. Drainage conditions often determine size of ridges or mounds and location of crops on them. Thus Okigbo (1978) illustrated the placement of different crops on large mounds in the hydromorphic areas of Southeastern Nigeria. There, cassava is usually planted on the side of ridges near the top, and the yams and legumes are planted on top. Crops tolerant to a high water table such as cocoyams (*C. esculenta*) and rice (*Oryza* sp.) are planted close to the base of ridges (cocoyam) and in the water-logged, flat intermound spaces (rice). In a study in the sandy-clay-loam soil in Zaire, there was no advantage in net yield from ridges as compared with flat or untilled plots where the field is mulched. Lowest yield occurred in unmulched, untilled fields (Table 1). In highly leached, low-fertility, clay-loam soil (Kimpese), ridging had no yield advantage over untilled plots, which produced the poorest yield, whether mulched or unmulched. No standing water was observed in either location. Okigbo (1979b) observed no effects of land preparation on root yield of cassava grown on flat ground, ridges, mounds, or untilled land. It would be worthwhile to conduct more trials on various soil types and in various ecological conditions. The extent of bush clearing may be unrelated to the land-preparation needs of a particular crop. Complete stumping for cassava culture may be done in forest areas prone to root rot caused by *Fomes lignosus*, for which several trees are alternate hosts.

Mafuku Method of Mound Preparation

A variant mound found in Central Africa, particularly Zaire, is called mafuku. Heaps of dry organic matter (grasses, broad leaves — any weeds) are partially buried with soil and set on fire. Part of the organic matter burns completely providing ash, whereas the deeply buried portion burns only partially because of the near anaerobic conditions. Mounds are constructed by the addition of fresh soil. Maize, peanuts, beans, melons, gourds, and vegetables are planted on the centre of the heap close to the partly burned residues, whereas cassava and sweet potatoes are planted further away but close to the ashes. Some 7–12 cassava stakes have been observed growing on a mafuku heap spaced 2.0 × 1.5 m (i.e. population of 40 000–67 000/ha). This high population would only be realized if the hectare had been systematically planted, and this is hardly the case in Bas-Zaire where random checks of eight farms revealed considerable gaps

Table 1. Effect of cultivation and mulching on cassava root yields from var. 02864 at two sites.

Cultivation treatment	Yield (fresh roots, t/ha) Site 1 (Mpalukidi) Mulch	Site 1 (Mpalukidi) No mulch	Site 2 (Kimpese) Mulch	Site 2 (Kimpese) No mulch
Flat	21.8	16.1	6.9	5.6
Ridge	17.4	13.9	8.0	4.8
No till	20.7	12.4	3.7	2.7
Mean	19.9	14.1	6.2	5.3
L.S.D. (0.05)	2.3	1.9	2.2	2.0

(Table 2). Although a peasant farmer's field may seem overpopulated, the gaps result in populations approaching those recommended in conventional planting. In the mafuku practice, a farmer concentrates the organic matter, together with its nutrient contents, which would serve a large area, into a much smaller area and, to compensate for loss in area, increases the number of plants on the heap. The position of a mafuku is usually shifted from year to year so that areas between mounds in one season will be the mounds in the next season. In other words, the mafuku land preparation system practiced by the Bakongos of Central Africa more or less constitutes a built in method of crop rotation.

Table 2. Cassava population on mafuku heaps in Bas-Zaire in 400 m^2 sample areas.

No. of heaps	Plants/heap (average)	Population/ha
52	9.0	11700
44	8.0	8800
38	11.5	10925
48	8.5	10200
46	7.0	8050
48	7.0	8400
56	6.5	9100
50	8.0	10000

Time of Planting

Time of planting depends upon many factors, the most important of which is the onset of rains. The associated crop in an intercrop also determines the time of planting of cassava, which may be planted late (June–August in northern hemisphere, March–April in southern hemisphere) or early (March–May in northern hemisphere, September–November in southern hemisphere). Higher yields are usually obtained from crops planted early because they are exposed to more months of rain (Nwosu 1973; IITA/PRONAM 1978; IITA 1977). In a study of the effects of delayed planting on root yield in southern Nigeria, average cassava dry root yield was reduced 11.0, 35.0, and 56% for respective delays of 1, 2, and 4 months (Table 3). On the other hand, in Zaire, planting very early when rainfall is not yet certain may result in poor establishment of plants and subsequent reductions in yield (Table 4). Given that November is the optimum planting time, one can expect average reductions in root yield at 1, 2, or 3 months delay to be 4, 29, and 34% respectively for a first-season crop. In Western Tanzania, Scaife (1968) reported a decline in root yield from 20 t/ha to only 5, (75%) by a delay in planting from December to March.

In South Western Zaire, first-season planting is usually from late September to January. October–December planting is usually recommended, and the common practice is to plant cassava early in combination with maize, peanuts, vegetables, and sometimes melons. Late-planted cassava (February–April) is in as-

Table 3. Effect of delayed planting on root yield (dry weight, t/ha) of late season cassava in southern Nigeria (adapted from IITA 1977).

Month planted	Cassava alone	% of June yield	Maize/ cassava	% of June yield	Cassava/ melon	% of June yield	Avg	%
June	10.81	100	9.53	100	11.19	100	10.51	100
July	9.72	90	8.94	94	9.38	84	9.35	89
Aug	6.91	64	6.54	69	7.04	63	6.83	65
Sept	6.70	62	8.14	85	7.91	71	7.58	78
Oct	4.48	41	4.71	49	4.38	39	4.52	44

Table 4. Effect of time of planting on root yield (fresh roots, t/ha) of early cassava in pure and mixed culture in central Africa, Zaire, (adapted from IITA/PRONAM 1978).

Month cassava planted	Cassava yield	Cassava yield when mixed with maize[a]	Avg yield as % of Nov yield
Oct	11.50	12.03	–
Nov	20.44	10.80	100
Dec	17.68	12.17	96
Jan	13.85	8.42	71
Feb	9.90	10.60	66

[a]In all cases maize was planted in October.

sociation with field beans, pigeon peas, sweet potatoes, or is alone. Late March–April or even May plantings are usually of cassava alone, which is often stunted and heavily attacked by insects, particularly mealybug (*Phenacoccus manihoti*) and green spider mite (*M. tanajoa*). Usually yields are low. It therefore appears that length of growing season, determined mainly by soil moisture conditions, decides the time to plant and the crop combinations for cassava production in subsistence farming in Africa.

Planting Methods, Pattern, and Spacing

Stakes, usually 25–30 cm long, are arranged in different patterns on ridges, mounds, flat or untilled plots. The use of disease-free planting material, preferably 12–18 months old (Godfrey-Sam-Aggrey and Bundu 1972) is recommended. Other observations are: (1) the older the stakes are, the higher the root yield and the better the plant establishment (IITA/PRONAM 1978; IITA 1974; Enyi 1970); (2) stakes are normally two-thirds buried with the older end in the soil; (3) optimum length of stakes is 20–40 cm, though longer ones do not result in yield losses (Nestel 1973); (4) root yield and plant establishment are significantly reduced when stakes are planted upside down (Onwueme 1978b), though this finding has not been established as fact (Nestel 1973); (5) given optimum soil moisture and soil temperature conditions, young stakes become established more readily than do stumps and primary stems. They also dehydrate and die more quickly in adverse conditions, e.g. moisture stress or water-logged conditions (IITA/PRONAM 1978).

Variations in planting methods include upright placement, horizontal, and, most common, slanted planting, in which two-thirds of the stake is buried old-end first, at an angle of 30–45° to ground surface. Effects of the different methods of planting on root yield are conflicting. Some results show no differences for the varieties studied (IITA/PRONAM 1978); others indicate improvement in root yield for different varieties in a slanted position (Umanah 1977); and still others note a significant increment in leaf yield and number of stems per plant as well as reduced lodging for horizontally planted stakes compared with those planted in an inclined or vertical position (IITA/PRONAM 1978). Onochie et al. (1973) have speculated that cassava planted vertically would be less favourable for mechanical harvesting than cassava planted in a horizontal or slanted position because of increased depth of rooting. The mould board plow or ridger used in their study could not easily reach the roots without damaging them.

The most primitive planting pattern and method is on a flat field, at random, with the planter usually moving up the slope or sideways and spacing often being determined by the length of the planter's stride or machete, or plans for intercropping. Populations of 18 000–28 000 plants per hectare have been observed at random in fields in forests and derived savanna areas of Zaire.

Cassava may be planted on mounds, ridges, or on flat, tilled, or untilled fields. Size and spacing of mounds vary with tradition, soil–water relations, and crop combination. When mixed with other crops, cassava stakes (2–16 per mound) are usually planted on the sides of the mounds. The number of stakes planted varies with location, number of crops per mound, size of mound, and soil–water relations. The size of mound may vary from 1.3 × 1.3 m in Abakalaki, southeast Nigeria (Okigbo 1978), to 1.0 × 0.8 m in Okigwi (personal observation 1976). Oversized heaps, 2 × 1.5 m, have been observed in Bas-Zaire. Up to 11 different crops per mound (including cassava) have been observed by Okigbo (1978). The range was 5–11.

On the basis of research, no spacing has been found to be universally applicable because spacing should vary with cassava variety, the rate of development of leaf cover, branching habit, dominant weeds, and soil moisture conditions (Enyi 1972; Akobundu 1980). Some reports show highest root yield at wide spacings 1.5 × 1 m (6600 plants/ha) (Ekandem 1967 in Okigbo 1979b), whereas others show highest yields at 1 × 1 m (10 000) and 1 × 0.67 m (15 000) (IITA 1974; Umanah 1977). In the forest zone of Ghana, Gurnah (1973) reported highest yield at 18 500 plants/ha. In general, a population of 10 000–15 000 plants/ha is economic and gives a good crop of cassava.

Planting arrangement may vary from 0.9 to 1.5 m between rows, the within-row spacing being adjusted to bring population to 10 000–15 000 plants/ha. A common variation in Zaire is double-row cassava planting — two rows of cassava spaced about 50 cm apart on ridges, 1 m apart. Plant spacing on each ridge is 1–1.5 m. Root yield from this arrangement is comparable with that from 1 m × 1 m spacing, but the double-row pattern tends to favour peanut productivity, especially at high peanut populations.

Systems and Sequence of Cassava Culture

Cassava is generally grown in mixtures with other crops, including yams, maize, cocoyams, plantain, sugarcane, beans, peanuts, melons, bananas, sweet potatoes, and assorted vegetables. Tree crops such as oil palm and cashew (E. Africa, Okigbo 1978) have also been observed in association with cassava, as has elephant grass (Nwosu 1973). Cassava is usually the last crop in a rotational system. Because cassava matures last and is usually harvested after the other crops, some observers surveying areas erroneously assume that cassava is being grown alone. Timing of such surveys is, therefore, important.

Cassava is increasingly being grown alone in large plantations; however; large operations contribute only a small percentage of total cassava production in Africa and are likely to continue to do so for awhile. Thus, the target in cassava improvement is still the small farmer.

Cropping combinations that involve cassava under various ecological conditions in Western Africa based on Okigbo (1978), Nwosu (1973), and Godfrey-Sam-Aggrey and Bundu (1972), include: (1) imperfectly developed monoculture based on cassava; (2) yam/cassava or pineapple/cassava; (3) yam/maize/cassava; (4) cocoyam/plantain/yam/cassava; (5) yam/cocoyam/maize/cassava; and (6) yam/cocoyam/pigeon pea/cassava.

Commonly observed combinations in Central and Eastern Africa include: (1) plantain/*Phaseolus*/cassava; (2) plantain/sweet potato/cassava; (3) sweet potato/cassava; (4) maize/peanut/cassava; (5) maize/beans/cassava; (6) beans or peanut/cassava; and (7) cassava as a monocrop in the Kalahari Sand areas.

Okigbo (1977b) observed best yield of cassava and maize and best returns per ha when both crops were planted at the same time or cassava was planted through maize after 1–2 months but not later. In Bas-Zaire, a preliminary observation was that yield reduction of cassava planted through maize 3 and 4 months later was 31% and 12%, respectively. Reduced insolation and sub-optimum temperatures under the maize canopy at 3 months are suspected as the main causes of yield reduction (IITA/PRONAM 1978). It is more profitable to intercrop cassava with other cash crops. The yield of peanuts planted at the same time as double-row cassava, or cassava planted at 75 × 100 cm or 100 × 100 cm spacings, depended more upon the peanut population than upon the cassava planting system, though double-row association was generally superior to the others. Intercropping produces maximum benefits when the cropping sequence and choice of crop minimize interplant competition for the limited environmental resources (light, water, nutrients, space, etc.) during critical periods of growth and development.

Because cassava has minimal demands for resources, it is commonly planted last in a sequence of crops, and the number of crops in combination with cassava decreases with increasing distance from the farmer's homestead (Nwosu 1973; Okigbo 1978). The farther away the field is located, the less likely it will be fertilized with refuse, etc., and the less demand will be put on it by the farmer.

Among the major cropping sequences involving cassava identified by Okigbo (1978) is a system of 3 years of heavy cropping with maize, vegetables, and other crops followed by early and late cassava mixed with legumes and vegetables in the 4th and 5th years. Whether alone or intercropped, cassava is usually harvested from fields that have been fallow.

Effect of Culture and Ecology on Scale of Operation

Because in Africa cassava is generally grown by low-income peanut farmers, there are understandable limitations on its production. Among the important factors that limit cultivation are:

(1) Plot preparation with simple tools. Using only simple hand tools and human power, a family can usually cultivate only a small area. Although some families draw on help from extended families, child labour, and, in rare cases, hired labour, plots rarely reach 5 ha per family. To spread the risk and diversify their crops, farmers sometimes own patches of intercropped cassava plots at several locations; for instance they may have cassava mixed with yams, cocoyams, maize, and vegetables in the more fertile forest zones; peanuts, pigeon peas, and beans in the dry sandy areas; yams, cocoyams, rice, and vegetables in the hydromorphic areas. The availability of the type of terrain needed for specific purposes, a factor related to population pressure and availability of labour for land preparation, may also limit the scale of operation.

(2) Weed competition. The most common method of weed control in cassava growing areas in Africa is hoeing. Cassava usually needs to be weeded at a time when there is a high demand on

the farmer's time for other farm operations such as harvesting peanuts and maize, preparing plots for bean and cocoyam cultivation, and maintaining compound farms. For good cassava root yield, weeding must be frequent and timely, especially during the first 12 weeks (Akobundu 1980; Moody and Ezumah 1974). Most farmers fail to weed early enough, and their losses are high. To be economic and meaningful, large-scale cassava production requires that weeds be controlled. Hoeing is too expensive, demanding about 41% of the time spent in cassava production. Excellent herbicides that have proved effective against weeds associated with cassava in forest zones of Nigeria have been identified by Akobundu (1980). The plots where such herbicides were applied produced root yield as good as weed-free plots. Again, the utility of the herbicides is limited by the mixed cropping system of cassava.

Choice of cassava variety may be helpful in controlling weeds. Akobundu (1980) has noted that TMS 30395 developed at IITA grows fast, produces extensive branches and leaf cover within 3 months of being planted, and thus has some natural means of weed control. Lal et al. (1979) identified some legumes and grasses that can be grown as cover crops, killed as sods with contact herbicides such as pararquat, and have maize, cowpeas, and cassava planted through them in untilled plots. Cassava produced well in this system, which, if perfected, may provide an answer to weed control in mixed cropping. In contrast, mulching (with organic matter), though suppressing weeds and improving root yields, is not practical because of the lack of available mulching materials, a problem recognized by Lal et al. (1979).

(3) Diseases and pests. In Africa, cassava is attacked by many diseases and pests, among which are African mosaic, cassava bacterial blight, and cassava anthracnose. Prevalent insect pests are the cassava mealybug, the green spider mite, and *Zenocerus* sp. Each of these diseases and pests causes considerable losses in root yield (IITA/PRONAM 1977; Nyira 1978) and reduces the scale of production and operation.

(4) Transportation of planting materials. Cassava stakes are heavy and difficult to carry given the resources of peasant farmers. This feature obviously limits the extent to which they can be conveniently moved. As most cassava diseases and pests are transmitted via stakes, there are stringent quarantine regulations that limit the dissemination of disease-resistant cultivars and, hence, their introduction in areas where they are badly needed.

Conclusions

Cassava-planting systems differ throughout Africa but are similar in that they are part of subsistence operations. The scale of cassava production is limited by drudgery in plot preparation and weeding, diseases and pests, transportation and difficulty, and obstacles to widespread adoption of scientific innovations in mixed cropping systems. A disturbing view expressed by Hahn et al. emphasizes the place of cassava in the diet. "Since it is a reserve food, 90% of which is consumed by humans in Africa, it is generally harvested when needed and when more attractive food crops are out of season or are destroyed by drought. Unless the trend is such that demands other than human consumption make production more attractive, the potential increase in production may be retained in the ground." Industrial demands for cassava, more efficient and faster processing methods, more easily accessible processing facilities, and a more affluent population, coupled with demands for cheap food by an ever-increasing population, are likely to increase the trend toward larger commercial cassava farms such as those gaining ground in Nigeria and other West-African countries, and in Zaire.

Cassava Planting Systems in Asia

Sophon Sinthuprama[1]

This paper is based on information obtained from India, Indonesia, Malaysia, and Thailand. It summarizes and compares the techniques and practices commonly used in Asia and the research that has been undertaken in Thailand. In most countries in South and Southeast Asia, cassava is grown as a sole crop. The crop can be planted any time of the year, except during heavy rains or in the dry seasons, if the distribution of rainfall is uniformly good. Cassava planted early in the rainy season has been found to give higher yield than cassava planted later.

Power for land preparation depends mainly on farm size and soil conditions and includes manual cultivation, animal-drawn tools, and tractors. The planting material is normally obtained from 7–18-month-old plants from the previous crop. Planting position varies depending on soil moisture, the method of operation, and tradition. Horizontal planting has been found to produce lower yields than vertical or inclined planting. Depth of planting had no effect when planting was either vertical or inclined. One stake is generally planted per hill in Asia, but there is a wide variation in row and plant spacing depending mainly on soil fertility.

Cassava is produced in nearly all countries of Asia. Indonesia is the principal cassava-producing country with an area of 1.36 million ha and production at 12.2 million tonnes in 1977. The other major producers in Asia are Thailand (10.6 million tonnes) and India (6.5 million tonnes). Thailand is the second in area and production but is the leading exporting country in the world.

Cassava is ranked as the third staple food, after rice and maize in Indonesia. In the Philippines it is primarily utilized as supplementary to the traditional staple food of rice and as livestock feed. In Malaysia cassava is not an important crop compared to rubber, oil palm, and coconut. In India as a whole, cassava is not a major crop. However, tapioca is widely served as a supplement to rice or even exclusively replaces it in the diet of the people in Kerala, which is the largest producer of tapioca in the country.

Cassava yield in Asian countries is considered low. Compared with a yield potential of 37 t/ha, the national average is about 15 t/ha in Thailand. Factors contributing to low yield of cassava are poor agronomic practices, low soil fertility, absence of fertilizer use, and probably use of low-yielding varieties.

[1]Head, Root Crop Branch, Field Crop Division, Department of Agriculture, Thailand.

Planting Time

Cassava can be planted throughout the year if the distribution of rainfall is uniformly good but not during heavy rains or in the dry season.

Planting is generally done at the start of the rainy season and toward the end of the rainy season. In Indonesia it is in October and in March–April; in Malaysia anytime, except in the east coast of Peninsular Malaysia where all agricultural operations could be interrupted by the heavy seasonal monsoon during November–December. In Thailand there are two major cassava areas; the Northeast with 64% of the cassava area followed by the East (29%). Soils in both regions are sandy loam to sandy, drought-prone, and low in available moisture and nutrients. In the Northeast, most of cassava is planted early in the rainy season, May–June. In the East rainfall commences earlier than in the Northeast. Plantings are done earlier in the rainy season (February–March) and in the late rainy season (November–December). In India it is in April–May.

A survey conducted in the growing area of

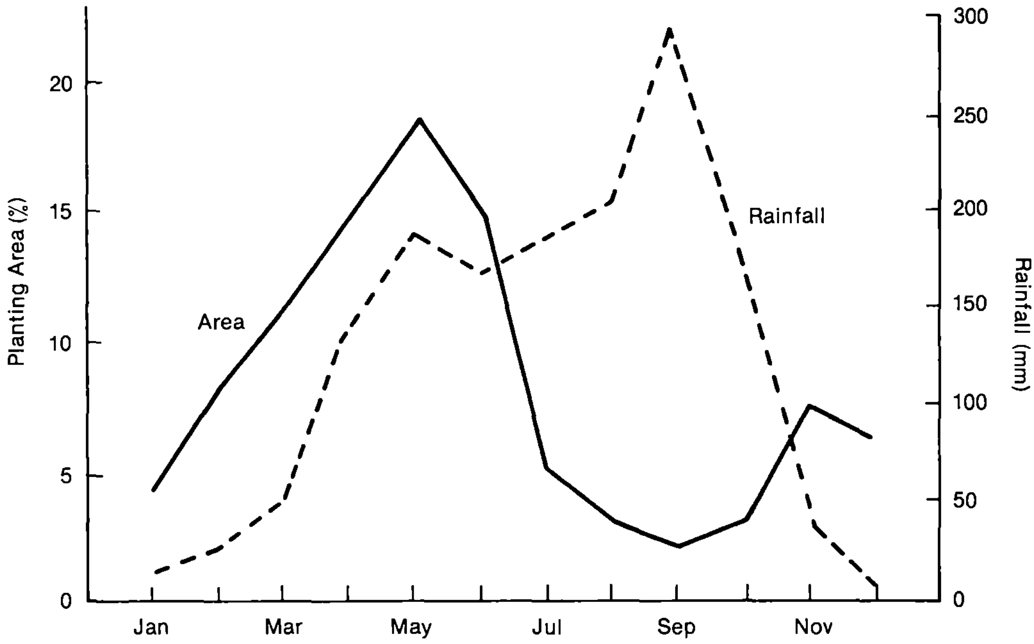

Fig. 1. Relationship between rainfall pattern and time of planting of cassava.

Thailand in 1975 showed that 18.53% of the crop is planted in May followed by 14.99% and 14.61% in April and June, respectively (Fig. 1).

Research findings are that early rainy season (May–June) planting of cassava gives higher yield than later planting (Table 1). Reasons for planting cassava late in the rainy season (November–December) are minimizing heavy weed problems, higher prices because of higher starch content, and high demand from chipping factories that utilize the sun-drying method. Planting or harvesting cassava during February does not cause competition for labour with rice.

Land Preparation

On small farms and farmers' yards, where the area is less than 1 or 2 ha, as in Indonesia, the Philippines, Malaysia, and some parts of Thailand, land is usually prepared manually or by the use of animal power. Usually two plowings are conducted, followed by one harrowing at the beginning of the rainy season.

On large farms, as in Thailand, some parts of Malaysia, the Philippines, and Indonesia, land preparation is by tractor. In Thailand and in Malaysia custom services for tractor plowing are

Table 1. Effect of time of planting and age at harvest on yield (t/ha) of cassava (1976–78).

Planting date	Harvest ages (months)						
	8	10	12	14	16	18	Avg
May	20.27	26.98	36.49	42.46	49.52	57.06	38.76
Jun	22.15	27.73	36.51	47.31	51.93	53.36	39.83
Jul	19.82	29.07	35.07	40.74	44.05	48.51	36.21
Aug	14.46	22.96	29.14	38.62	39.57	43.68	31.41
Sept	12.25	17.64	28.65	32.48	34.59	36.26	26.98
Oct	8.16	16.69	22.17	23.95	29.52	32.61	22.18
Avg	16.18	23.51	31.33	37.56	41.53	45.25	

L.S.D. (0.05) for planting date × harvested ages = 4.92 (t/ha).

available. Usually the land is plowed once with a 3–5-disk plow followed by 7-disk plow once or twice. Sometimes it is plowed twice with a 5–7-disk plow because the soil is loamy sand or sandy. Plowing is done as soon as possible after the harvest of the previous crop. A major problem of land preparation is a lack of a sufficient number of tractors, which results in delayed planting.

Recommendation: plow 15–20 cm deep once or twice with a tractor to bury stems of previous crops, follow by harrowing once or twice. When the land is prepared this way, stakes can be planted directly in the soil without furrowing.

Stake Preparation

There is not much variation in the preparation of stakes throughout Asia. Planting material is obtained from the previous crop or from a neighbour's field free of charge. During the large expansion of cassava area in Thailand, new growers had to buy planting material. Stakes are usually taken from 10–12-month-old plants from a previous crop, which is usually harvested at 12 months in Thailand, 8–18-month-old plants in the Philippines, and 7–8-month-old plants in Indonesia.

At harvest, whole stalks are bundled and stacked upright or piled horizontally in the field under shade or in the open and sometimes covered with leaves until they are required for planting.

It is recommended that stakes be taken from 6–12-month-old plants so that survival rate is more than 90%. CIAT recommends that planting material be taken from plants ranging from 8 to 18 months of age. When a new cultivar is to be rapidly multiplied, the first stakes may be taken 6 months after planting and the subsequent ones every 6 months.

The period of storage of planting material is dependent on the receipt of rains for land preparation and ranges from 15 to 90 days, usually 30 days in Malaysia and Thailand, and 45–90 days in Indonesia.

Storage of no longer than 30 days is recommended so that survival rate is not less than 80% (Table 2). When the stakes are to be planted, the immature herbaceous part at the top and too-woody part at the base of the stalk are removed. Then stakes of desired length are prepared: Malaysia 15 cm; Indonesia 20–25 cm; Philippines 20–30 cm; Thailand 15–25 cm, more usually 10–20 cm.

Table 2. Survival percentage of plants from stakes stored under different conditions and for various periods (1976–78).

Storage (days)	Storage conditions: Under shade	Open	Covered with leaves
0	95.61	95.31	96.50
15	93.47	93.38	91.60
30	83.39	84.28	87.89
45	80.02	55.98	58.36
60	57.50	48.86	50.03
75	49.23	31.96	43.11
90	44.90	28.94	35.87
105	43.19	21.03	22.09

Results from experiments conducted in Thailand in 1966 showed that yields are not significantly affected by length of the stake in the range of 10–30 cm even though shorter stakes give a lower survival percentage.

Stakes have between 3 and 7 nodes, but it is more usual to use 5–6-node stakes for planting in Thailand. Cutting is at an angle, which makes it easy to insert the stake into the soil. CIAT recommends stakes at least 20 cm long with 5–7 nodes that should have a pith diameter of not more than 50% of the diameter of the stem. Cutting at an angle is not recommended. Generally stakes are not treated in any of the countries in Asia. CIAT recommends insecticide and fungicide treatments.

Planting Techniques

In all countries in Asia, cassava planting is done either on flat ground or on ridges, depending upon rainfall, soil condition, weeds, ease of harvest, and tradition. Ridge planting is done when the soil is likely to be wet, when the weed problem is severe, and when ease of harvesting is important. Flat planting is easy to practice and is preferred in low-moisture soil and in areas with less-assured rainfall. In Malaysia and the Philippines both methods are practiced. In Indonesia, in good soil, flat-planted cassava is intercropped with other food crops while a sole crop of cassava is ridge planted. In India the pit method is most popular followed by the mound method. In Thailand the majority of farmers prefer flat planting. A furrow is opened by an animal-drawn plow. For ridge planting, the ridge is usually prepared by animal-drawn plow once or twice to make the ridge 15 cm high. Distance between ridges varies. It is 120–180 cm in Malaysia, 100

Table 3. Yield of cassava roots (t/ha) with different methods, positions, and depths of planting.

	Depths of planting (cm)			
	5	10	15	Avg
Ridge	27.73	29.37	28.60	28.57
Flat	30.81	31.08	29.10	30.33
Flat, later earthed up	30.60	27.33	26.79	28.24
Vertical	30.88	31.12	30.37	30.79
Inclined	30.67	29.00	27.96	29.21
Horizontal	27.60	27.67	26.17	27.14
Avg	29.71	29.26	28.17	

NOTE: No interaction between methods, positions, and depths of planting.

in Thailand and the Philippines. Results from experiments in Thailand showed no difference in yield between the methods (Table 3).

Planting position varies depending on the moisture in the soil, ease of operation, and tradition. In Malaysia, horizontal planting is preferred because it takes less labour. In the Philippines, also, planting is usually horizontal. In India and Indonesia, vertical planting is preferred, whereas in Thailand, horizontal planting is practiced by those who plant very early or late in the rainy season when rainfall is uncertain. Vertical and inclined planting are more commonly practiced in Thailand. The major reasons are greater ease of harvest and less damage by weeds than with horizontal planting.

Depth of planting is variable. With horizontal planting, depth is about 3–5 cm, but in vertical planting it is about 10 cm. Results from experiments conducted in Thailand in 1977–78 showed that root yields were not different for cassava planted on ridge, flat, or flat followed by earthing up 30 days after planting. Horizontal planting gave lower yields than vertical mainly due to lower survival rates (Table 3). Vertical or inclined plantings were not different in survival percentages or yields (Table 3). Depth of plantings (5, 10, 15 cm) had no effect when plantings were either vertical or inclined (Table 3). Deeper plantings in the horizontal position resulted in delayed emergence of the sprouts.

One stake is generally planted per hill in all the Asian countries except in India where more than one stake is planted and thinned down to two shoots at 2 months.

There is a wide variation in row widths of cassava mainly because of the differences in soil fertility. It is 70–90 cm in India, 120–180 cm in Malaysia, and 75–100 cm in the Philippines and Thailand.

Plant-to-plant distance is 60–90 cm in Malaysia, 60–100 cm in Thailand depending upon soil fertility, 75–100 cm in the Philippines, and 75–90 cm in India. Results from an experiment conducted in Thailand in 1967–68 showed that yield is nearly invariant from 60 × 60 cm to 120 × 120 cm spacing. The normally recommended spacing is 100 × 100 cm; and in low-fertility soils and on slopes 80 × 100 cm is suggested.

Planting in the rainy season gives a high survival rate of 80–90% in Thailand and 90% in Indonesia, but planting late in the rainy season in Thailand decreases the survival rate to as low as 50%. Gap filling, if done, is usually within 30 days of planting. Replanting is done if survival is less than 50%.

The author is grateful to Chan Seak Khen, Research Officer, MARDI, Malaysia, to J. Wargiono, CRIA Root and Tuber Crops Coordinator, Indonesia, and to the staff of the Field Crop Experiment Stations in Thailand for making their data and experience available during the preparation of this paper.

Double Row Planting Systems for Cassava in Brazil

Pedro Luis Pires de Mattos, Luciano da Silva Souza, and Ranulfo Correa Caldas[1]

Cassava (cultivar BGM-001) has been planted for 2 years in a double-row system at Cruz das Almas, Bahia. Cassava border rows produce higher yields than inside rows because they receive more light and nutrients. This is called a border effect. The double-row system tries to use this principle. A spacing of $2 \times 0.6 \times 0.6$ m was shown to offer the highest productivity and greatest income return rate. Branch and stem production decreased as spacing increased between rows and along the rows; however, the number of roots per plant increased as the spacing between and along the rows increased.

The use of the double-row system for cassava offers the advantages of allowing other crops to be planted between the double rows, facilitating mechanical weeding thus reducing labour and other costs, providing better conditions for field inspection and chemical application, reducing the time required for soil preparation by 75%, and, finally, producing higher yields than conventional cassava cropping systems.

Cassava is grown in Brazil on approximately 2 million ha, holding sixth place in planted area as compared to other crops and producing about 25 million tonnes of roots annually. It contributes more than 10 billion cruzeiros to the national agricultural income.

In spite of the privileged position of Brazil in relation to other countries, and of the important role of cassava in Brazilian agricultural production, cassava production systems are quite unsatisfactory, mainly due to traditions and the lack of technology adoption. Among the possible cultural practices that could be used to increase yields are the use of more adequate spacing and good soil preparation, which result in the success of subsequent practices. In cassava, where the main product is the roots, there is a greater need for good soil preparation.

Planting cassava in double rows brings together two rows of cassava and leaves a greater space between these double rows than with the traditional method (Fig. 1). Because it has certain advantages when compared with the traditional planting system, this system can improve crop production by: (1) allowing easy use of mechanical equipment; (2) decreasing production costs due to a reduction of labour; (3) presenting the possibility of continuous use of the same area by alternating rows; (4) allowing the possibility of multiple cropping; (5) making crop inspection easy; (6) increasing productivity due to a border effect; (7) making the application

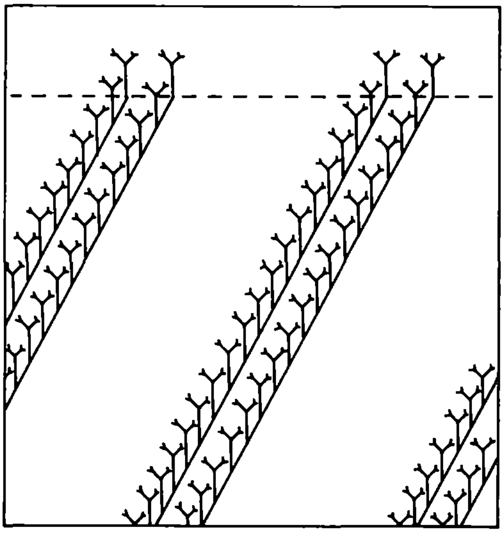

Fig. 1. Distribution of cassava in double-row planting system.

[1]Agricultural Engineers, EMBRAPA/CNPMF, Cruz das Almas, Bahia, Brazil.

of pesticides to control pests and diseases easy; (8) allowing the possibility of mulching with plants in the free spaces, for enriching the soil with organic material; (9) reducing the amount of fertilizer used; (10) reducing soil preparation to only the planting areas; and (11) making better use of the land.

For many crops (corn, soybean, wheat, etc.) minimum soil preparation is superior (plowing the whole planting area or plowing only the planting line strips) to the traditional method (plowing, disking, and land leveling). This is due to the following advantages: (1) maintenance of the desired soil structure, particularly by reducing compaction because less machinery is used; (2) reduction in soil loss due to erosion, and increased water availability to plants due to increased water infiltration into the soil, which decreases runoff; and (3) highly reduced operating costs (Shanholtz and Lillard 1969; Mannering et al. 1968). An adequate system of soil preparation for cassava is required because cassava is highly susceptible to water erosion.

Material and Methods

Trials were carried out during 1977–78 and 1978–79, at the headquarters of the National Research Center for Cassava and Horticulture of the Brazilian Research Center (Empresa Brasileira de Pesquisa Agropecuária, EMBRAPA) in Cruz das Almas, Bahía, Brazil. This research centre is located at 12°40′ S, 39°06′ W at an altitude of 220 m in a red-yellow oxisol having intermediate texture and low fertility (pH in water = 5.0; 9 ppm of P, 65 ppm of K, 1.6 meq/100 mg of Ca + Mg, and 0.2 meq/100 mg of Al). It has an Aws climate in transition between Af and Aw, according to the Köppen classification, that is to say a hot and humid climate, with a dry season compensated by high total humidity.

Spacing Adaptation in Double Rows

Experiments were carried out in random blocks with subdivided plots. Plots had 5 double rows with 48 plants each, with spaces between the plots. Subplots (cultivars) had 5 rows of 25 plants, and the 3 central rows with 20 plants each were harvested. Planting was carried out in furrows using 20-cm-long stakes planted horizontally at a depth of 10 cm.

Two cultivars were studied, BGM-116 (erect type) and BGM-001 (branching type). The following data were recorded: (1) root production; (2) starch production; (3) aerial part production; (4) number of roots per plant; and (5) economic data.

The soil was plowed, disked, and improved (according to chemical analysis) with dolomitic limestone (500 kg/ha) applied to the entire experimental area, followed by a second disking perpendicular to the first. Mineral fertilizer, composed of a mixture of 80 kg/ha of P_2O_5 + 40 kg/ha of K_2O in the form of triplesuperphosphate and potassium chloride, was applied to the furrows at planting. Mineral nitrogen in the form of urea (60 kg/ha of N) was divided into two doses and applied by mulching 45 and 90 days after planting.

The treatments that were studied included: 2.0 m, 2.5 m, and 3.0 m between double rows and 0.5 m, 0.6 m, and 0.7 m between the lines making up the double rows, plus a control with spacings of 1.0 × 0.6 m (Table 1).

As an initial weed-control measure, a herbicide mixture was applied that was composed of Diuron + Alachlor in doses of 1.0 kg a.i./ha + 1.5 a.i./ha, respectively, along the double rows after planting.

Reduction of Soil Preparation

The treatments studied were: (1) annual plowing of the whole area, disking, furrowing, and planting, mechanical harvesting between double rows, and manual harvesting in planting lines; (2) annual plowing of the whole area, disking, furrowing, and planting, manual harvesting in planting lines, and fertilizing with green legumes between double rows; and (3) plowing only of the double rows, disking, furrowing, and planting, mechanical harvesting between double rows, and manual harvesting of the planting lines.

Due to the need for large experimental plots for these treatments, planting was done in plots of 600 m^2, without replication. For computing average results, 10 plots with 36 useful plants were evaluated in each treatment. Data were statistically analyzed using an experimental design with three treatments and 10 replications.

The BGM-001 cultivar was used at spacings of 2.5 × 0.5 × 0.5 m, in double rows and harvested 12 months after planting. Cowpeas were used as the fertilizer in those treatments that use legumes planted between the double rows.

The soil in the experimental area was limed with 800 kg/ha of dolomitic limestone. A basic fertilizer was applied — 80 kg/ha of P_2O_5 (triplesuperphosphate) and 40 kg/ha of K_2O potassium chloride. Broadcast application of

Table 1. Effect of spacing on root and starch production of cassava cultivars BGM-116 (erect) and BGM-001 (branching) during 1977–78 and 1978–79.

Treatment (spacing in metres)	Plants/ha	BGM-116 Root production (t/ha)	BGM-116 Starch production (t/ha) 1977–78	BGM-116 Starch production (t/ha) 1978–79	BGM-001 Root production (t/ha)	BGM-001 Starch production (t/ha) 1977–78	BGM-001 Starch production (t/ha) 1978–79	Double rows/ha
2.0 × 0.5 × 0.5	16000	22.1	6.8	6.2	32.8	10.1	8.9	40
2.0 × 0.6 × 0.6	12820	34.1	10.4	7.0	39.7	12.1	10.1	38
2.0 × 0.7 × 0.7	10582	25.8	8.1	6.7	32.2	10.1	9.3	37
2.5 × 0.5 × 0.5	13333	27.6	8.7	6.6	28.5	9.1	8.8	33
2.5 × 0.6 × 0.6	10752	23.3	7.2	6.6	30.3	9.2	9.1	32
2.5 × 0.7 × 0.7	8928	23.1	7.1	6.4	29.1	9.0	7.6	31
3.0 × 0.5 × 0.5	11428	19.1	5.9	5.2	26.3	8.1	8.8	28
3.0 × 0.6 × 0.6	9259	20.1	6.3	5.3	28.0	8.4	8.0	27
3.0 × 0.7 × 0.7	7722	20.1	6.1	5.3	28.5	8.7	7.9	27
Control (single rows)								
1.0 × 0.6	16666	21.8	6.6	—	34.4	10.7	—	100

Table 2. Results of reduced soil preparation for cassava, as compared to the traditional system during the first planting year.

Treatments	Final[a] useful stand	Root production (t/ha)	Total aerial production (t/ha)	Starch (%)	Starch (t/ha)	Roots/ plant	Plant height (m) 6 months	Plant height (m) 12 months
Plowing whole area	5.85ab	25.8a	8.5a	32.5a	8.4a	6a	1.53b	1.70a
Plowing whole area+legumes	5.75a	27.9b	8.4a	32.7a	9.1a	7b	1.44a	1.68a
Plowing only double rows	5.91b	32.0b	12.6b	32.6b	10.7b	8c	1.66c	2.02b
L.S.D. (Tukey 5%)	0.15	4.2	5.6	0.8	1.4	0.2	0.07	0.12
C.V. (%)	2	13	28	2	12	7	9	14

[a]Data expressed as a square root.

fertilizer (60 kg/ha of N as urea) was done 45 days after planting.

The following data were recorded: (1) plant height after 6 months; (2) plant height after 12 months; (3) useful final stand; (4) root production; (5) production of aerial part usable for planting; (6) production of aerial part; (7) starch content (%); (8) starch production; (9) root length; (10) number of roots per plant; and (11) facility of manual harvesting (%) = (weight of buried roots/weight of harvested roots + weight of buried roots) × 100.

Work should be repeated in the same place for several years if the effects of soil preparation on the soil's physical properties are to be adequately evaluated. Crops will be alternated between double rows and intrarow spaces will be varied in subsequent cultures in the same area.

Results and Discussion

Space Adaptation in Double Rows

There were differences between the spacings and cultivars studied (Table 1) because space adaptation in double rows (2.0 × 0.6 × 0.6 m) increased root yields 57% and 16% in relation to the control treatment (1.0 × 0.6 m), for cultivars BGM-116 and BGM-001, respectively. The low yield percentage of cultivar BGM-116 is due to harvesting 10 months after planting (second experiment) and to slower growth of BGM-001 type. The average yield from the two cultivars increased 32% in the first experiment and 21% in the second experiment. The 2.0 × 0.6 × 0.6 m spacings were constant in the four replications of the experiment. Other treatments did not differ among each other and 2.0 and 2.5 m spacings between double rows yielded the same as the control treatment.

Regarding the average percentage of starch, there was no difference between spaces or cultivars, the content varying only from 30 to 31%. However, when starch production per area (t/ha) was considered, a high root yield in the 2.0 × 0.6 × 0.6 m treatment accounted for a highly significant increase in starch production compared with other spacings.

Based on the average of the two cultivars, the interaction of spacings between double rows and the spacing between the rows making up the double rows and the spacing between the plants showed that with 0.6-m spaces along the lines and between the plants, higher yields were obtained with smaller spaces between the double rows (2.0 m). This indicates that spacings can be reduced to a certain extent. Half a metre intrarow spaces and along lines showed better yields were obtained with 2.5-m spaces between the double rows. Decreasing the space between double rows produced a sharp fall in yields indicating that as space between rows and along the lines is decreased, it is necessary to increase the spacing between double rows. In the second experiment better yields were obtained when the space between double rows was increased to 2.5 m. However, when the space was increased to 3.0 m, the same decrease as the one observed in the first experiment was shown.

With the 0.7-m space between and along the lines, better yields were obtained with 2.0-m spaces between double rows. Further increases produced a sharp decrease in yields that may be attributed to low plant density.

The 2.0-m space between double rows showed the best results with optimum yields at 0.6-m spacings between and along the lines making up the double rows. Yields dropped again in a 0.7-m spacing. The 2.0-m spaces imply populations below 16 000 and above 10 000 plants/ha, with 13 000–14 000 plants/ha being the optimum.

The 2.5-m space between double rows produced maximum yields when the space between and along lines was 0.5 m. Yields decreased as the spaces increased.

In the two experiments carried out with 3.0-m spaces between double rows, the lower yields were possibly due to the small population of this treatment.

In the first experiment (stakes and stems), production of aerial parts of the plants decreased as the space increased, not only between double rows but also between and along the lines making up the double rows. In the second experiment, space interaction between double rows, intrarows, or along the lines making up the double rows, showed a production decrease as spaces increased between and along the lines of the double rows. The same happened in intrarows and along the lines making up the double rows. This implies a stronger competition for light and consequently greater development of the aerial parts.

The number of roots per plant increased, as the space between and along the lines of the double rows increased, due to an increase in the exploitation area per plant with greater spacings. This did not happen when the spacings between double rows varied because the number of roots per plant was constant.

The use of the herbicide mixture Diuron + Alachlor along double rows, associated with a quick shadowing of the ground, avoided weed development during the first 8 months up to the point where weeding was not necessary.

An economic analysis of this work showed that spacing adaptation in cassava planted in double rows is an advantageous practice, because all treatments had an income return rate higher than the control treatment.

Reduction of Soil Preparation

Results obtained during the first planting year (Table 2) showed the reduced soil preparation system to be superior (soil preparation restricted to the planting lines) to soil preparation of the whole area. This is true with or without multiple cropping with legumes as green fertilizer. Santos (1967) found a decrease in cassava production as soil preparation decreased. Intercropping cassava with legumes as green fertilizer was no different from treatments not employing this practice.

The superior performance of the system using reduced soil preparation in relation to the conventional one and to the conventional plus legumes as green fertilizer could be attributed to the fact that plowing only the double row leaves an open furrow on one side where rainfall converges, providing a higher humidity concentration in the planting lines and consequently making more water available to the plants.

Another favourable aspect of the reduced soil preparation system is that there is a time saving of 75%, which consequently reduces soil preparation costs. Considering the current fuel saving policy this is an important factor.

Double-Row Planting System

In some Brazilian regions planting cassava in double rows is becoming popular even though research data are not available.

Northeast

In the city of Maranhao, this practice is known by the farmers as *pàso de boi* (oxen step). It is done in 1.0 × 0.4 × 1.0 m spacings and rice is planted in the free spaces. In Sergipe, double-row planting is still under research and has not yet been adopted by farmers.

Southeast

In Espirito Santo State, work carried out by a farmer using 2.0 × 0.5 × 0.5 m spacings in an area of 8 ha under normal planting in single rows produced yields of only 19 t/ha (27% less than in double-row planting).

South

In Santa Catarina State, cassava planted in double rows with a spacing of 2.5 × 0.5 × 0.5 m in an area of 3 ha, in association with corn (*Zea mays* L.) (one row between the double rows), produced an average corn yield of 1755 kg/ha. Because cassava in that region is grown in two cycles with a compulsory pruning at the end of the first cycle to protect branches from frosts, sorghum planted at the start of the second cycle will allow farmers to harvest sorghum twice in one cassava culture without damaging the latter. Data on cassava production are not presented because it has yet to be harvested. Currently in Santa Catarina it is common practice among farmers to plant cassava in double rows in association with rice and soybeans.

Conclusions

Cassava planting in double rows is an advisable practice because besides increasing root and starch yields and profitability, it allows the free spaces to be used for growing other species such as beans, soybeans, sorghum, rice, peanuts, millet, sweet potatoes, and tobacco.

The 2.0 × 0.6 × 0.6 m spacings showed the highest productivity and the greatest income-return rate.

Based on data obtained in the first planting year, the reduced soil preparation system (restricting soil preparation to planting lines) in cassava planted in double rows produced better performance than conventional preparation (soil preparation in the whole area) in relation to production of roots and aerial parts, starch percentage and number of roots per plant, and plant height 6 and 12 months after planting. In addition, the reduced soil preparation system provided a 75% savings in costs regarding soil preparation as compared with conventional preparation.

Soil-Related Cultural Practices for Cassava

Reinhardt H. Howeler[1]

Intensification of cassava production in recent years has brought about a change in cultural practices toward greater mechanization in land preparation and harvest and the use of chemical rather than organic manures. Care must be taken to maintain soil fertility and structure and to control erosion. Erosion control practices that should be investigated include minimum tillage, mulching, green manuring, intercropping, contour planting, and strip cropping. The observed decline in soil fertility under continuous cassava production may be due to nutrient loss by erosion as well as to crop removal. Cassava tends to enhance erosion and hence nutrient loss. Also, the crop removes large amounts of nutrients, especially K and N, in each root harvest.

Cassava is well adapted to very acid and infertile soils but may require high levels of fertilization to obtain maximum yields. However, the crop is sensitive to overfertilization, which causes excessive top growth and little root growth. The use of large amounts of inorganic fertilizers may also lead to serious nutritional imbalances on low-fertility soils. Determinations of the optimum rate of fertilization and the proper balance of nutrients are of great importance. These should be based on soil and plant analyses as well as on fertilization trials. More information on critical nutrient levels in soils is needed for the interpretation of soil analyses and the making of fertilizer recommendations. The choice of source, and time or method of application, can be based more on practical and economic considerations because, in general, only small agronomic differences have been observed when these factors are varied.

In the past, cassava was largely grown as a subsistence crop and used principally as human food or animal feed. Although cassava was generally grown on the poorest soils, farmers seldom used chemical fertilizers, relying instead on simple cultural practices such as periodic burning of forest regrowth, crop rotations, intercropping, green manuring, or applications of compost or animal manure to maintain the soil fertility. The plant was considered as an efficient nutrient extractor, if not a soil exhauster, and was often grown as the last crop in a rotation before the nutrient-depleted soil was returned to bush-fallow. Cassava is still grown under much the same conditions throughout the lowland tropics. In Colombia the use of chemical fertilizers for cassava production is essentially nil (Diaz and Pinstrup-Andersen 1977) even though cassava is grown on soils that are very low in pH, P, and K (Diaz et al. 1977), and significant fertilizer responses have been amply demonstrated (Tarazona et al. 1973). Similarly, in Thailand, the second largest producer of cassava in the world (FAO 1979), the crop has been grown continuously for more than 25 years without fertilization in the Sattahip soils of the southeast (Sittibusaya and Kurmarohita 1978). It is only recently that interest has developed in the large-scale production of cassava for animal feed or as the raw material for the production of starch and alcohol. Under these conditions cultural practices change entirely, the crop becomes essentially a monocrop, and machinery is utilized for land preparation, harvest, and applications of chemical inputs (chemical fertilizers tend to replace the use of organic manures as these are not easily available in large quantities and their transport and application may be too costly). This intensification of cassava production may have serious consequences if proper care is not taken to control erosion, preserve soil structure, and maintain adequate soil fertility conditions. This paper reviews the results of research on soil-related cultural practices so as to recommend the use of proper practices and determine future research needs.

[1]Soil Scientist, Cassava Program, CIAT, Cali, Colombia.

Soil Conservation and Erosion Control

Cassava is a crop that tends to enhance soil erosion and should therefore not be grown on steep slopes. Gomez (1975) reported that on a volcanic ash soil with 60% slope in Colombia a cassava crop lost over 10 t/ha of soil in 28 months due to erosion and that 30% of the soil was lost in only 5 days shortly after harvest. He calculated a relative erosion index of 11.8 for coffee, 9.8 for cassava, 1.7 for pineapple, 1.1 for sugarcane, and 1.0 for pasture. Cassava soils are particularly erodable after planting because of wide spacing and slow canopy closure, and also shortly after harvest because of soil loosening, especially that caused by mechanical harvesters. Unfortunately cassava is often the only crop that will still grow under the adverse soil conditions of eroded slopes, thus further enhancing soil erosion. This practice should be limited as much as possible or combined with effective erosion-control practices.

(1) *Minimum tillage:* Lal (1976) showed that no-tillage practice in a maize–cowpea rotation under humid tropical conditions of Nigeria reduced soil loss to essentially zero compared with 11 t/ha soil loss for a conventional cowpea–maize rotation and 58 t/ha for bare fallow. Little is known of the response of cassava to minimum tillage practices. When the native savanna in the Llanos of Colombia was not tilled, but only burned off and subsequently controlled with herbicides and hand weeding, cassava yields declined from 16 to 10 t/ha. Superficial tillage with sweeps or one harrowing was not effective in loosening the compacted soil, which impeded cassava root formation. Highest yields were obtained with a conventional tillage practice of harrowing-plowing-harrowing-bedding. However, these data apply only for the highly compacted native savanna soils and may be irrelevant for cultivated soils where previous tillage practices might have loosened the soil. The effect of soil compaction and minimum tillage on cassava yield has yet to be determined quantitatively, but in principle as little tillage as possible is recommended for erosion control. The use of herbicides instead of tillage for weed control is recommended as it does not disturb the soil and leaves a mulch of dead weeds to protect the soil from the impact of raindrops.

(2) *Mulching:* In Nigeria the application of 4–6 t/ha of straw mulch effectively prevented runoff and soil loss from slopes ranging from 1 to 15% (Lal 1976). This was comparable to a no-tillage treatment. Mulching also reduces high soil temperature, reduces nutrient loss in water runoff and sediments, conserves soil moisture, improves infiltration, and helps to control weed growth (Lal 1976; CIAT 1979). Table 1 shows that different mulches vary in their effectiveness mainly due to differences in persistence. Maize stalks, sugarcane leaves, and grass straw were most persistent and increased cassava yields in two sites in Colombia.

(3) *Covercrops or intercrops:* The use of intercrops is commonly practiced in cassava subsistence cropping systems and has the advantage of producing a cash crop after only a few months; it helps to cover the soil quickly after planting and thus controls runoff and erosion. This practice also reduces weed growth and rapid

Table 1. The effect of mulching practices on cassava root yield, soil temperature, and weed control at harvest in Carimagua (cv. M Ven 168) and CIAT (cv. M Mex 59).

	Carimagua			CIAT-Palmira	
Mulching practices	Root yield (t/ha)	Soil temp. (°C)	Weeds (t/ha)	Root yield (t/ha)	Soil temp. (°C)
Check with weed control	10.3ab	25	—	24.9ab	23
Check without weed control	8.7b	28	31.2	23.1abc	23
Mulch of loosened soil	8.7b	27	—	22.3abc	23
Mulch of plantain leaves	10.4ab	28	27.0	—	—
Mulch of maize plants	12.8a	26	17.0	27.3a	22
Mulch of grass (*Hyparrhenia rufa*)	12.5a	27	23.5	—	—
Mulch of kudzu	12.4a	27	27.5	—	—
Check with irrigation	10.1ab	29	—	17.9c	23
Mulch of rice straw				22.9abc	23
Mulch of cassava leaves/stems				19.1bc	24
Mulch of sugarcane leaves				26.1a	23
Mulch of *Stylosanthes*				25.8a	23

NOTE: Treatments followed by the same letter are not significantly different at $p = 0.05$ within each location.

dissemination of diseases and insects and may contribute microbiologically fixed N from intercropped legumes. In Bali, Nitis and Sumatra (1976) obtained a 17% yield increase by intercropping cassava with *Stylosanthes guyanensis*, and Nitis (1977) reported that the intercropped stylo supplied about 9 kg N/ha to the cassava without additional fertilization and 72 kg N/ha when fertilized with P, K, and micronutrients. However, the covercrop or intercrop should be carefully chosen so as to tolerate the same soil and climatic conditions as cassava and not to compete excessively for light (climb on the cassava plants), water, or plant nutrients. Although intercropping can greatly increase the combined yields of both crops, expressed as land equivalent or area-time equivalent ratios (CIAT 1978), it seldom has a direct beneficial effect on cassava yields. Depending on the competition from the intercrop, cassava yields were depressed from 0 to 50% in Carimagua and CIAT-Quilichao (Fig. 1).

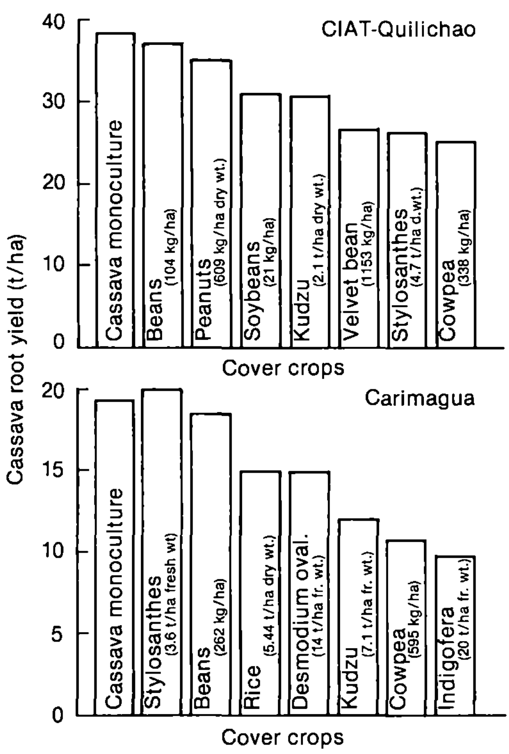

Fig. 1. The effect of several cover crops on fresh root yield of cassava grown at CIAT-Quilichao and Carimagua (all yields of cover crops are for grain unless otherwise indicated).

(4) *Contour planting:* Contour planting is common on hill sides, especially where the land is prepared by animal traction. Little research has been done on the effectivenss of this method in controlling erosion in cassava.

(5) *Strip planting:* On long or steep slopes, contour planting should be combined with strip planting in which strips of cassava are alternated with strips of less-erosive plants such as pasture or sugarcane. If legumes are used as the strip crop, they can be incorporated as green manure before planting. The next cassava crop is planted in these strips, and the previous cassava strips are planted with legumes. For this purpose a nonclimbing cowpea cultivar may be an attractive strip crop as it grows well in the same ecosystem as cassava, the plant covers the soil quickly, the pods or seed can be harvested, and the vines incorporated into the soil. As a green manure, cowpea was more effective than other crops (CIAT 1975) in the acidic soils of the Llanos of Colombia.

Maintenance of Soil Fertility

Cassava extracts large amounts of nutrients from the soil and if not adequately fertilized will exhaust soil nutrients. Sittibusaya and Kurmarohita (1978) reported that after 15 years of continuous unfertilized cassava production in southeast Thailand, yields dropped from an initial level of 30 t/ha to only 17 t/ha. When the soils were fertilized with 375 kg N, 164 kg P, and 312 kg K/ha, yields increased from 22 to 41 t/ha. (To prevent confusion, all nutrients are expressed on an elemental basis, not in the oxide form.) In Indonesia Doop (1937) found that three consecutive cassava plantings without applied potassium (K) decreased yields from 15 to 4 t/ha. However, various long-term experiments have shown that, if adequately fertilized, good yields of continuously grown cassava can be maintained (Birkinshaw 1926; Hongsapan 1962; Ofori 1973).

Hongsapan (1962) considered that per tonne of food produced cassava depeleted soil nutrient reserves less than maize, sugarcane, bananas, or cabbage. However, on a per crop basis, cassava extracts more nutrients than most other tropical crops (Kanapathy 1974).

According to Prévot and Ollagnier (1958), among tropical crops cassava extracts the largest amount of K from the soil, as it has the highest K/N ratio in the harvested product. Table 2 shows the amount of nutrients in the whole plant and in the roots per tonne of cassava roots

Table 2. The amount of nutrients (kg/ha) removed per tonne of harvested cassava roots.

Plant part	Root Yield (t/ha)	N	P	K	Ca	Mg	Reference
Roots	40	1.83	0.37	1.82	0.36	1.08	Dulong (1971)
Roots	52.7	0.72	0.53	5.08	0.65	0.37	Nijholt (1935)
Total plant		2.50	0.92	9.04	3.06	0.99	Nijholt (1935)
Roots	64.6	0.70	0.44	4.91	0.79	0.28	Nijholt (1935)
Total plant		1.93	0.70	7.53	2.40	0.66	Nijholt (1935)
Roots	6	1.00	0.29	2.64			Hongsapan (1962)
Roots	42	3.64	0.40	4.40	0.60	0.14	Dufournet and
Total plant		6.02	0.67	5.95	1.00	0.69	Guarin (1957)
Roots	26	6.85	0.77	3.50	1.00	0.12	Dufournet and
Total plant		10.96	1.38	4.69	2.15	0.46	Guarin (1957)
Roots	25	2.20	0.19	1.60			Dias (1966)
Roots	50	3.06	0.34	3.70	0.50	0.12	Cours (1953)
Total plant		5.06	0.56	5.00	0.84	0.58	
Roots	—	3.00	0.50	3.50	0.60	0.10	Cours (1953)
Total plant		5.00	0.80	5.00	1.20	0.50	
Roots	2.6	1.49	0.49	2.11			Mejia-Franco (1946)
Roots		2.02	0.43	3.02			Kanapathy and
Total plant		6.28	1.89	6.53			Keat (1970)
Roots	21	1.01	0.44	2.09	0.37	0.48	Kanapathy (1974)
Total plant		4.10	1.77	6.43	2.15	1.63	Kanapathy (1974)
Roots	30	2.00	0.71	7.05			De Geus (1967)
Roots	40	2.12	0.66	5.74	1.32		De Geus (1967)
Roots	10	3.92	0.90	9.90	0.35		Obigbesan (1977)
Roots	9	3.63	0.88	9.67	0.40		Obigbesan (1977)
Roots	31	1.00	0.61	1.52			Sittibusaya and
Total plant		2.35	1.03	2.32			Kurmarohita (1978)
Average							
Roots		2.33	0.52	4.11	0.61	0.34	
Total plant		4.91	1.08	5.83	1.83	0.79	

harvested. On average, cassava extracts per tonne of roots about 2.3 kg N, 0.5 kg P, 4.1 kg K, 0.6 kg Ca, and 0.3 kg Mg when only the roots are removed from the field. Thus, a yield of 25 t/ha of cassava roots removes 57 kg N, 12 kg P, 102 kg K, 15 kg Ca, and 7 kg Mg. However, if the top growth was harvested as well, this would increase to 122 kg N, 27 kg P, 145 kg K, 45 kg Ca, and 20 kg Mg/ha. Thus, cassava extracts large amounts of nutrients from the soil, but the return of stems and leaves to the field considerably reduces soil depeletion.

Besides nutrient extraction by the crop, soil fertility may decline due to erosion, and Sittibusaya and Kurmarohita (1978) mention that this may have been the principal cause of cassava soil exhaustion in southeast Thailand. Lal (1976) in Nigeria reported highest nutrient losses in runoff water from a 15% bare slope of 13.4 kg N, 2.5 kg P, 20 kg K, 14 kg Ca, 2.7 kg Mg/ha during one season. Mulching with 4–6 t/ha of straw essentially reduced runoff to zero. In addition, he reported nutrient losses in sediments of 27–126 kg N, 3.5 kg P, 12 kg exchangeable K, 8.4 kg exchangeable Ca, and 11 kg exchangeable Mg/ha. Again mulching reduced these losses substantially. Thus, an effective control of erosion and the return of plant tops to the soil are very effective practices to reduce nutrient loss and fertilizer requirements.

Fertilizer Requirements

To maintain soil fertility it is necessary to return to the soil at least those nutrients lost through crop removal or erosion. Therefore, rather large amounts of K and N have to be added to counteract the relatively large losses in the cassava root harvest as well as in runoff and erosion sediments. Losses of P, on the other hand, are relatively small; still P-deficiency is one of the most common nutritional factors limiting cassava production, especially in Latin America, and rather large amounts of applied P are required for maximum cassava yields. This is due to the low level of available P in most tropical soils, and their high P-fixing capacity; it is also due to the inefficiency of the cassava root system to absorb P, at least in the absence of a mycorrhizal association (Howeler et al. 1979). Calcium and magnesium are also lost in rather small amounts. Sufficient amounts of Ca are generally applied in lime or superphosphates, but Mg may have to be applied as a separate fertilizer as the crop appears to be susceptible to Mg deficiency.

Although adequate fertilization is required for maximum yields and maintenance of soil fertility, excessive fertilization can easily reduce yields and cause pollution of waterways. Cock (1975) has shown that cassava has an optimum leaf area index of 2.5–3.5 and that high rates of fertilization may lead to excessive top growth and a leaf area index of more than 4. High rates of fertilization also result in a decrease in harvest index (CIAT 1977, 1978), indicating that proportionally less dry matter produced is transported to the roots. Thus, cassava is very sensitive to overfertilization, which causes it to be excessively leafy, particularly at high plant populations (CIAT 1979). Moreover, nutrients seldom react independently but, instead, interact with each other. Thus, Howeler et al. (1977) and Edwards and Kang (1978) showed that high rates of lime application induced zinc (Zn) deficiency and reduced cassava yields. Spear et al. (1978b) showed that high concentrations of K in solution reduced the uptake of Ca and Mg, while Ngongi et al. (1977) reported that high application rates of KCl resulted in severe S deficiency. Hence, the proper level of fertilization and the right balance of nutrients applied is of utmost importance.

Use of Organic Manures

Traditionally cassava has been fertilized only with organic manures such as green manures, compost, wood ash, and farmyard manure (FYM), and even today that is the common practice among subsistence farmers or in areas where these manures are readily available. They may be of particular importance in sandy soils to improve water- and nutrient-holding capacity. In Madagascar, investigators (Anon. 1952, 1953) recommended incorporation of FYM or green manure such as *Mucana utilis, Vigna,* or *Crotalaria. Vigna* (cowpea) is well adapted to the same ecological conditions as cassava and has been found to be a superior green manure on the acid infertile Llanos soils of Colombia than *Indigofera,* velvet bean (*Stizolobium deeringianum*) and *Crotalaria* (CIAT 1975). *Crotalaria* was particulary susceptible to soil acidity and did not produce well at a pH of less than 5 (CIAT 1974).

De Geus (1967), Kumar et al. (1977), and Mandal et al. (1973) indicated that cassava responds well to applications of FYM, especially when fortified with some chemical fertilizers (CTCRI 1974; CIAT 1977). In southern India, a 66% yield increase was obtained by the application of 15 t/ha of FYM (CTCRI 1970). In Zanzibar, Tanzania, a doubling of yield from 19 to 36.5 t/ha was reported with the application of 22.6 t/ha of FYM, whereas no yield increases were obtained with $(NH_4)_2SO_4$ or KCl (Anon. 1961). In the Ivory Coast, Botton and Perraud (1962) obtained a 21% yield increase with FYM and a 5–10% increase with home sewage. Lambourne (1927) reported better results with FYM (10 t/ha) than with chemical fertilizers or green manures (basic slag and *Crotalaria*). In the rather isolated and largely beef-producing areas, such as the Llanos of Colombia and Venezuela and the Campo Cerrado of Brazil, cattle manure is often available around corrals, whereas costs to obtain chemical fertilizers can be prohibitive. Wood ash is essentially the only fertilizer used in slash and burn agricultural systems. It is a good source of bases, especially K, and thus of great value for cassava production. In the Peruvian jungle at Yurimaguas the burning of the Amazon rain forest supplied only enough nutrients for the cultivation of upland rice for 1–3 years before yields declined drastically (NCSU 1975).

In India, wood ash is a common K fertilizer (CTCRI 1973, 1974, 1976). In areas of Brazil where charcoal is a commonly used energy source for industry, the resulting wood ash might also be utilized as a K fertilizer for cassava.

Use of Inorganic Fertilizer

Although organic manures may be superior or more economic under certain special circumstances, inorganic fertilizers are required for large-scale cassava production and are generally more effective and economic because of higher nutrient contents and thus lower transport and application costs. The nutrient content of commonly used fertilizers and organic manures are shown in Table 3. The choice between organic or inorganic fertilizers is mainly one of economics because plants absorb nutrients in the same inorganic form from either source. Moreover, levels of organic matter in the soil can be maintained or increased with inorganic fertilizers as these tend to produce more crop residues, which upon incorporation become part of the soil organic matter. A rapidly established and dense ground cover, resulting from proper fertilization, will also reduce erosion and nutrient losses. The effectiveness of applied fertilizers depends on the method of application as well as the time and rate of application of each nutrient, which all depend on the soil, the climate, and to some extent, the cultivar to be grown.

Method of Fertilizer Application

Cassava has a coarse root system with a small number of relatively thick roots and few root hairs (Howeler et al. 1979). For this reason it may be highly dependent on a mycorrhizal association for nutrient uptake (Zaag et al. 1979; Yost and Fox 1979). Campos and Sena (1974) and Sena and Campos (1973) reported that at 7 months cassava roots reached a depth of 90 cm but that 66% of the roots were present in the top 10 cm of soil and that at 12 months roots reached a depth of 140 cm with 86% in the top cm of soil. Thus, it appears that cassava has some deep roots, possibly for water absorption during droughts, but that the bulk of the root system is very superficial, making applications of fertiliz-

Table 3. Nutrient content (%) of commonly used organic and inorganic manures (adapted from Jacob and Uexküll 1973).

	N	P	K	Ca	Mg	S
Organic manures						
Cow manure (dry)	2.0	0.65	1.67	2.86	0.60	0.2
Horse manure (dry)	2.0	0.65	1.25	1.07	0.60	0.2
Chicken manure (dry)	5.0	1.31	1.25	2.86	0.60	0.8
Wood ash	—	0.87	4.20	23.2	2.11	0.4
Inorganic manures						
Ammonium nitrate	33	—	—	—	—	—
Mono-ammonium phosphate	11	21	—	—	—	—
Di-ammonium phosphate	21	23	—	—	—	—
Ammonium sulfate	20.5	—	—	—	—	23
Calcium ammonium nitrate	20.5	—	—	7-14	—	—
Calcium nitrate	15.5	—	—	20	—	—
Potassium nitrate	13	—	37	—	—	—
Sodium nitrate	16	—	—	—	—	—
Urea	45	—	—	—	—	—
Urea formaldehyde	38	—	—	—	—	—
Simple superphosphate	—	6.5	—	17-22	—	12
Triple superphosphate	—	20	—	12-16	—	—
Basic slag	—	6.5	—	32-35	1-3	0.2
Rhenia phosphate	—	12.7	—	29	0.6	0.4
Potassium chloride	—	—	50	—	—	—
Potassium sulfate	—	—	42	—	—	18
Potassium magnesium sulfate	—	—	18	—	11	22
Magnesium sulfate	—	—	—	—	10	13
Magnesium oxide	—	—	—	—	32	—

ers to depths beyond 10–20 cm probably ineffective. Using radioactive P, Ofori (1970) established that once the roots start functioning as carbohydrate sinks, they no longer play an active role in nutrient absorption. He also confirmed that the actively absorbing roots were mainly present in the top 10 cm of soil.

Normanha and Freire (1959) obtained poor sprouting when N and K were applied in the planting row, especially during the dry season. They recommended lateral placement of P and K at planting with a top dressing of N at 3 months (Normanha 1961; Normanha et al. 1968; Silva 1965). However, in the Llanos of Colombia placement of 1 t/ha of 10-20-20 fertilizers directly under either the vertically or the horizontally planted stake was not detrimental even during dry-season planting, as long as the stake was not in direct contact with the fertilizer (CIAT 1979). Broadcasting half of the fertilizers and banding the other half at planting was found to be the best method during wet-season planting (CIAT 1979). In a trial in Darien, Colombia, Ramirez (1978) found no significant difference between banding, circle, or spot placement of a compound NPK fertilizer, and in Thailand broadcasting, banding under the stake, or side banding at 20 or 50 cm were found to be equally good practices (Sittibusaya et al. 1974). In Malaysia, Chan (1970) found no significant differences between broadcasting or spot dressing of N at planting. With the application of triple superphosphate (TSP) in the Llanos of Colombia, no differences were observed between band or broadcast application (CIAT 1976), although in more highly P-fixing soils band application is expected to be superior. For less-soluble P sources, such as rock phosphates or basic slag, broadcasting was highly superior to banding (CIAT 1976). In India, higher yields were obtained with placement of P at 5- or 10-cm depth than with surface placement (CTCRI 1971).

Time of Application

Several researchers (Normanha 1961; Silva 1965; Samuels 1970; Mandal et al. 1971) have recommended that N and K fertilizers be applied at or shortly after planting with an additional top dressing at 2–3 months. Kumar et al. (1971) reported best results in India with the application of half of the K at planting and half at 1 month. In the same country, Ashokan and Sreedharan (1977) recommended a split application of K if only small amounts are applied, while CTCRI (1970) reported highest yields with split application of N (1/2 basal, 1/2 at 2 months), P (1/2 basal, 1/2 at 1 or 2 months) and K (1/2 at 1 and 2 months), although in other trials (CTCRI 1971) a basal application of P was found to be significantly superior to split application of this element. Rodriguez (1975) obtained highest yields when NPK fertilizers were applied at planting rather than as a split application. CIAT (1976, 1978) found no significant differences between a basal or split application of either N or K fertilizers, but that a basal application of P was superior to a split application (CIAT 1976). More recently (CIAT 1979), a split application of K with one-third applied at 0, 30, and 90 days was found to be superior to a basal application.

Rate of Application

The correct rate of application of the various nutrients depends entirely on the soil fertility and texture. Fertilizer recommendations are generally based on soil analyses and fertilizer experiments, while corrective applications can be made based on foliar analyses. To aid in the interpretation of analytic results, many investigators have determined the relationship between plant growth (or yield) and the "available" nutrient content of the soil or the total nutrient content of a certain index tissue of the plant, generally the youngest fully expanded leaves (YFEL). The plant's nutritional requirement is reported in terms of "critical concentrations," i.e. the concentration of a nutrient in the soil or plant tissue, below which the plant will respond to the application of that nutrient and above which no such response is to be expected. Generally it is defined as the concentration corresponding to 90 or 95% of maximum yield.

Critical concentrations in soils for cassava have been reported for only a few elements and their usefulness is limited because of the great diversity in methods of soil analyses. Table 4 shows the critical concentrations reported in the literature. Much more information on critical concentrations and a greater standardization in analytic procedures are urgently needed. Soil pH is probably the most important parameter for diagnostic purposes because soil pH determines the availability of many essential plant nutrients. In very acid soils, P, Ca, Mg, Cu, Zn, and Mo may be deficient whereas Mn, Fe, and Al may be in excess. At high pH on the other hand, P, K, Fe, Mn, B, and Zn, may be deficient (Maynard 1979).

Critical nutrient concentrations in cassava tissue reported in the literature are summarized

Table 4. Critical levels of soil parameters for cassava.

Parameter	Level	Method of analysis[a]	References
pH	4.6 and 7.8	1:1 soil-water ratio	CIAT (1976, 1978)
Al	2.5 meq/100 g	1 N KCl	Howeler (1978)
Al sat.	80%	Al/Al + Ca + Mg + K	CIAT (1978)
P	7 μg/g	Bray I-extract	Howeler (1978)
	10 μg/g	Bray II-extract	Howeler (1978)
	8 μg/g	Olsen-EDTA extract	Howeler (1978)
	9 μg/g	North Carolina extract	Howeler (1978)
K	0.15 meq/100 g	NH_4-acetate	Obigbesan (1977)
	0.09–0.15 meq/100 g	NH_4-acetate	Obigbesan (1977)
	60 μg/g	North Carolina extract	Howeler (1978)
	0.06 meq/100 g	—	Roche et al. (1957)
Ca	0.25 meq/100 g	NH_4-acetate	CIAT (1978)
Conductivity	0.5–0.7 mmhos/cm	Saturation extract	CIAT (1976)
Na sat.	2.5%	NH_4-acetate	CIAT (1976)
Zn	1.0 μg/g	North Carolina extract	Howeler (1978)
Mn	5–9 μg/g	North Carolina extract	Howeler (1978)
SO_4-S	$\simeq$ 8 μg/g	—	Ngongi et al. (1977)

[a]Bray I = 0.025 N HCl + 0.03 N NH_4F
Bray II = 0.1 N HCl + 0.03 N NH_4F
Olsen-EDTA = 0.5 N $NaHCO_3$ + 0.01 M Na-EDTA
North Carolina = 1 N HCl + 0.025 N H_2SO_4
NH_4-acetate = 1 N NH_4-acetate at pH 7.

Table 5. Critical nutrient concentration for deficiency and toxicity in cassava plant tissue.

Element	Plant tissue	Concentration[a]	References
N def	YFEL[b] leaf blades	5.1%	Fox et al. (1975)
	Shoots	4.2%	Forno (1977)
	YFEL leaf blades	5.7%	Howeler (1978)
	YFEL leaf blades	4.65%	CIAT (1976)
P def	Shoots	0.47–0.66%	Jintakanon et al. (1979)
	YFEL leaf blades	>0.44%	CIAT (1977)
K def	YFEL leaf blades	1.1%	Spear et al. (1978a, b)
	YFEL petioles	0.8%	Spear et al. (1978a, b)
	Stems	0.6%	Spear et al. (1978a, b)
	Shoot and roots	0.8%	Spear et al. (1978a, b)
	YFEL leaf blades	1.2%	Howeler (1978)
	YFEL petioles	2.5%	Howeler (1978)
Ca def	Shoots	0.4%	Forno (1977)
Mg def	Shoots	0.26%	Edwards and Asher (unpublished)
	YFEL leaf blades	0.29%	Edwards and Asher (unpublished)
S def	YFEL leaf blades	0.32%	Howeler (1978)
Zn def	YFEL leaf blades	60μg/g	CIAT (1976)
	YFEL leaf blades	37–52μg/g	CIAT (1977)
	YFEL leaf blades	43–60μg/g	Edwards and Asher (unpublished)
B def	Shoots	17μg/g	Forno (1977)
B tox	Shoots	140μg/g	Forno (1977)
Mn def	Shoots	100–120μg/g	Edwards and Asher (unpublished)
Mn tox	Shoots	250–1450μg/g	Edwards and Asher (unpublished)
Al tox	Shoots	70–>97μg/g	Gunatilaka (1977)
	Roots	2000–14000μg/g	Gunatilaka (1977)

[a]Range corresponds to values obtained with different cultivars.
[b]YFEL = youngest fully expanded leaves.

in Table 5. In general, one might conclude that a fertilizer response is not likely when the YFEL blades contain more than 5.0% N, 0.4% P, 1.2% K, 0.7% Ca, 0.3% Mg, 0.35% S, 17 μg/g B, 8 μg/g Cu, 100 μg/g Fe, 100 μg/g Mn, and 60 μg/g Zn. A toxicity may be suspected if plant tops contain more than 140 μg/g B, 100 μg/g Al, or 1000 μg/g Mn.

Table 6. The response of cassava to the application of major nutrients (kg/ha) and lime (t/ha) in different parts of the world as reported in the literature. Numbers underlined indicate the principal limiting nutrients, while a dash indicates no response.

Country	Region	Soil	N ←	P kg/ha	K	Mg →	Lime t/ha	References
Puerto Rico		Ultisol	120				2	Fox et al. 1975
					83		2	Samuels 1970
Costa Rica			60–70	26–30	108			Schmitt 1955
			50	—				Acosta and Perez 1954
		Lateritic			—			Murillo 1962
Colombia	Various	Incept-oxisol	50–60	<u>131</u>	42–50			Tarazona et al. 1973
	Antioquia	Inceptisols	145	85	38			Rodriguez 1975
	Cauca Valley	Mollisols			100			Ngongi 1976
	Llanos	Oxisols	100		200	50		Ngongi 1976
	Llanos	Oxisols	100					CIAT 1975
	Llanos	Oxisols		87–175	133			CIAT 1976
	Llanos	Oxisols					0.5–2	CIAT 1977, 1978
	Llanos	Oxisols				60		CIAT 1979
Peru	Tarapoto	Ultisol	—	52	—			Curva 1977
Brazil	São Paulo, Goias			<u>26–52</u>	25-83		2	Normanha 1951, 1960, 1961
	São Paulo	Sandy	—	—	50–100			Silva and Freire 1968
	Rio de Janeiro			29	—			Nunes et al. 1974
	Minas Gerais	Oxisols			50			Correa et al. 1979
	Bahía	Oxisols	200	<u>30</u>	—			Santana et al. 1979
	Bahía	Oxisols		<u>26–52</u>	50–100			Gomes et al. 1979a
	Amazon estuary			44	150			Albuquerque 1968
Nigeria	Western		25	—	50			Amon and Adentunji 1973
	Western	Various	60–90		—			Obigbesan and Fayemi 1976
	Eastern	Light, acid	<u>9–27</u>		17			Irving 1956
		Ultisol					1–1.6	Edwards and Kang 1978
Ghana			25	10				Stephens 1960
		Forest ochrosol	60	20	—		—	Takyi 1972
	Otrokpe		134					Takyi 1974
Madagascar			30–60	57	<u>92</u>			Anon. 1952, De Geus 1967
			100	—	<u>150</u>			Roche et al. 1957
			30	120	<u>100</u>			Cours et al. 1961
India	Kerala	Oxisol	100					Mandal et al. 1971
	Kerala	Oxisol	100–150					Saraswat and Chattiar 1976
	Kerala	Oxisol	<u>50–100</u>	44–65	83			CTCRI 1970, 1971, 1972, 1973
	Kerala	Oxisol	100	44–65	83			Vijayan and Aiyer 1969
	Kerala	Oxisol		35	133			Chadha 1958
	Kerala	Oxisol			83			Kumar et al. 1971
Thailand				14–21				Hongsapan 1962
	Northeast	Podzols	<u>50–100</u>	22–44				Sittibusaya and Kurmarohita 1978
	Southeast	Exhausted podzols	<u>50–100</u>	44–88				Sittibusaya and Kurmarohita 1978
Malaysia	Southeast	Peat	<u>180</u>	22	92–133		3	Chew 1970, 1971
	Southeast	Peat	120	—	75			Kanapathy 1974
	Kuala Lumpur		150	30	150	20		Cheing 1973
	Serdang		124	29	98			Ahmad 1973
Indonesia	Java		90	13	0–42			Hadi and Gozallie 1975
	Java	Inceptisols	—		125–250			Doop 1937

Fertilizer experiments with cassava have been done throughout the tropical world, but the results are often only of local value unless the soil and climate are well characterized so that extrapolation to other areas with similar conditions is possible. In this respect much can be improved in cassava fertilizer research. The responses to individual elements in various parts of the world have recently been reviewed (Howeler 1980). On a regional basis they are summarized in Table 6.

P is the main limiting nutrient throughout tropical America, but N and K are more limiting in Africa and Asia. Only in the peat soils of Malaysia is the micronutrient Cu the main limiting element, whereas symptoms of Zn deficiency have been observed in both acid and alkaline soils throughout the world. Cassava appears to be particularly susceptible to an inadequate supply of this element, especially at the early stage of growth when the plant has not yet developed an adequate root system. A severe Zn deficiency, which can reduce yields to nearly nothing, can easily be induced by overliming (Howeler et al. 1977; Edwards and Kang 1978). Cassava in general is very tolerant of acid soil conditions such as low pH, and high levels of exchangeable Al or available Mn. CIAT (1978) reported a response to liming only when the pH was less than 4.6 and the Al saturation was more than 80%. However, in high organic matter soils such as those of CIAT-Quilichao (8–9% O.M.) cassava tolerated a pH as low as 3.9 and 85% Al (CIAT 1979) whereas in low O.M. soils it may be sensitive to less severe acid conditions. In soils low in Ca, Mg, and P, such as many oxisols and ultisols, liming with dolomitic lime may be beneficial to supply Ca and Mg while improving the availability of P (CTCRI 1970) and Mo. However, in general, cassava requires little or no lime.

Sources of Fertilizers and Soil Amendments

Nitrogen can be applied in either the nitrate or the ammonium form (or both), but little is known about the form it is actually taken up as by the cassava plant. Forno (1977) reported that in flowing solution culture cassava had an external nitrate requirement that was more than 10 times as high (3400–4650 μM) as its ammonium requirement (26–420 μM). This would indicate that the plant can absorb or utilize ammonia more effectively than nitrate. However, in field-grown cassava, no significant differences were observed between NH_4 sources such as urea, and $(NH_4)_2SO_4$ and NO_3 sources such as $NaNO_3$ or $Ca(NO_3)_2$ (Samuels 1970; Santana et al. 1975; CTCRI 1969, 1970). However, $CaNH_4(NO_3)_3$ was found to be a superior source in India, probably because of its Ca content (CTCRI 1969). The slow-release N source of sulfur-coated urea (SCU) was not found to be superior to urea in Colombia (CIAT 1974), Puerto Rico (Fox et al. 1975), or Nigeria (Agboola and Obigbesan 1976), nor were other slow-release N fertilizers better than a split application of urea in Thailand (Nopamornbordee et al. 1967).

The most commonly used P sources are single or triple superphosphate, although basic slag was found to be equally effective and where available is generally a more economic source (CIAT 1976; CTCRI 1971). In highly acid soils of the Llanos of Colombia, various rock phosphates of high citrate-solubility were equally effective as triple superphosphate (TSP); less-soluble sources were nearly as effective in subsequent years (CIAT 1977, 1978). Mixing of rock phosphates with sulfur or sulfuric acid improved the P availability of the rock phosphate considerably (CIAT 1976).

Potassium is generally applied as KCl, which is cheaper and has a higher K content than K_2SO_4. Both these sources, as well as wood ash, syngenite, and schoenite, were all found equally effective in southern India (CTCRI 1973, 1974). In the Cauca Valley of Colombia KCl and K_2SO_4 were also equally effective, but in the low-S soils of the Llanos of Colombia K_2SO_4 or KCl mixed with sulfur was superior to KCl alone (Ngongi et al. 1977).

Calcium is generally applied as $CaCO_3$ (lime), $Ca(OH)_2$, or CaO, although the more soluble source $CaSO_4$ (gypsum) may be more effective in low-S soils. Magnesium can be applied as dolomitic lime, MgO, or $MgSO_4 \cdot 7H_2O$. The latter was superior to MgO in low-S soils of Colombia (Ngongi 1976), but other experiments in similar soils failed to show any significant differences between Mg sources. Dolomitic lime was the most economic source under Colombian conditions. Sulfur is in general adequately supplied with other nutrient sources, but in low-S soils special care should be taken to select S-bearing fertilizers or to apply an additional amount of elemental sulfur or gypsum.

Zinc can be applied as ZnO to the soil, or as $ZnSO_4 \cdot 7H_2O$ to the soil or foliage; it can also be employed as a 2–4% $ZnSO_4$ solution as a treatment for stakes before planting — found especially effective in high-pH soils at CIAT (CIAT 1977).

Summary and Conclusions

Cassava extracts large amounts of nutrients from the soil, especially K and N, and may exhaust the soil's nutrient reserves unless adequately fertilized. Returning the leaves and stems to the field considerably reduces the nutrient removal and the amount of fertilizer to be applied. Also cassava is a crop that tends to enhance erosion because of slow canopy closure after planting and a thorough loosening of the soil during harvest. It is therefore not recommended to grow cassava on steep slopes and, if necessary, this must be combined with effective erosion-control measures such as minimum tillage, mulching, cover or intercrops, contour planting, and strip cultivation. Without these measures large amounts of nutrients may be lost in runoff water and sediments, thus accelerating soil exhaustion as well as soil loss. Cassava grows relatively well on very infertile soil but may require high levels of fertilization for maximum yields. However, because fertilization tends to stimulate top growth more than root growth, the crop is sensitive to overfertilization. The right amount and right balance of fertilizers are therefore of utmost importance.

In the oxisols, ultisols, and many inceptisols, commonly found in tropical America, cassava responds mainly to P with minor responses to N, K, Mg, and lime. In Africa and Asia, soils tend to be of higher fertility, and cassava experiments have shown, mainly, responses to N and K — elements that are easily leached out or removed in large quantities during harvest. Of the minor elements, Zn is commonly deficient, although Cu deficiency seriously affected yields on the peat soils of Malaysia. Most cassava cultivars are very tolerant to acid soils, requiring little or no lime, and severe micronutrient deficiencies can be induced by overliming.

Research Priorities

Because cassava production will extend more and more into areas of marginal soils, it is essential to focus more attention on research of soil-related problems. The following areas appear to justify special attention:

(1) Research on genetic tolerance to adverse soil conditions and the incorporation of this tolerance into high-yielding cultivars.

(2) Research on the relation between soil characteristics and cassava production, and determination of minimal levels of available nutrients required for near-maximum production.

(3) Research on the use of cheap sources of plant nutrients such as rock phosphates, organic manures, industrial waste products, etc.

(4) Research on the most efficient fertilizer application techniques including development of adequate machinery and tools.

(5) Research on the nutritional value of fallowing, rotations, and intercropped legumes.

(6) Research on efficient methods of erosion control such as minimum tillage, mulching, cover crops, contour planting, and strip cultivation, as well as on harvesting techniques that minimally loosen and expose the soil.

(7) Research on mycorrhizae and other microorganisms that may affect nutrient uptake, especially the development of simple practices that enhance a plant-microorganism association.

(8) Research on the interaction between plant nutrition and tolerance to diseases and insects.

Only through a coordinated international research effort can we expect to cover all these research topics adequately. It is necessary to obtain a better understanding of all that has already been investigated and establish research priorities to solve some of the soil-related problems that still limit cassava production.

Soil and Water Conservation and Management for Cassava Production in Africa

H.C. Ezumah, R. Lal, and B.N. Okigbo[1]

Increases in food production in the tropics have always been associated with increases in land area. Thus as populations increase more and more land is sought for food production. The result has invariably been deforestation and soil degradation resulting from the erosion that is associated with high and intensive rainfall in the tropics. Soil management methods to arrest this trend have received attention in recent years. In this paper, consideration is given to a number of methods generally employed in soil and water conservation. These include the use of mulch; minimum tillage; land preparation and bush clearance methods that reduce erosion and ensure rapid regeneration of bush fallow; live mulch, sod, and green manure management; selective weeding; and mixed and relay cropping to ensure continuous vegetative cover during the year.

The potentially cultivable area in the tropics is 5×10^9 ha, out of which 1.25×10^9 ha may be classified as agriculturally useful land. The percentage of cultivated land area is 22, 83, and 11 in Africa, Asia and South America, respectively. A considerable area of potentially cultivable land in the humid and subhumid tropics is now under primary or secondary forest cover. Approximately 10 million ha of forest are cleared annually by the shifting cultivators. Boerma (1975) estimated that the arable land area in tropical countries may have to be increased from 737×10^6 ha in 1970 to 890×10^6 ha in 1985 to maintain present nutritional levels for the world population. In addition to this shifting cultivation currently practiced, the rate of annual new land development for commercial farming in the tropics may be 6–10 million ha. If these large-scale land development schemes can be successfully implemented, there is a hope for increased food production. However, the implementation of similar schemes elsewhere in the tropics has proven to be disappointing.

One of the factors that leads to rapid degradation of soil productivity following deforestation in the tropics is soil erosion. Soil erosion is a serious hazard because of high climatic erosivity, low structural stability, and low soil loss tolerance. Traditionally cassava is grown in association with other crops that offer a multistorey canopy cover throughout the rainy season. This continuous ground cover protects the soil surface against splash, crusting, and shearing effects of excessive overland flow. This system of cultivation, though soil conserving, can only be effective as long as the length of fallow period is adequate to permit rejuvenation of soil structure and buildup of the nutrient reserves in the surface horizon. If the system breaks down due to a shortening of the fallow period because of demographic pressure, soil degradation due to accelerated erosion can be a serious problem even under traditional systems of farming.

Complete removal of native vegetation for commercial cassava production, either as a sole crop or in association with other crops, can aggravate soil erosion (Mouttapa 1973; Tourte and Moomaw 1977; Lal 1979). Among the factors affecting soil erosion, climatic erosivity and soil erodibility are fixed parameters that cannot be manipulated. However, land use and crop and soil management practices are the most important controlling factors that influence structural properties of the soil and hence runoff and soil erosion. The basic principles of soil erosion control are simple and well established. One must aim at those land use and soil management practices that ensure economic and continuing

[1]Agronomist, Soil Physicist, and Agronomist, respectively, IITA, Ibadan, Nigeria. The senior author is currently Agronomist/Project Leader, IITA/Program National Manioc, Republic of Zaire.

soil and water conservation. In general, preventive measures are to be given preference over corrective measures because the latter are expensive and it is often too late to adopt remedial measures.

Basic Principles of Soil Conservation

Soil erosion involves detachment of soil particles from aggregates and transportation of the detached particles to another place. The energy to perform this work is provided by raindrop impact and by the shearing effect of concentrated water runoff. The shearing effect increases with slope steepness and runoff velocity. Effective erosion control, therefore, lies in reducing the direct impact of raindrops, maintaining maximum soil infiltrability, and decreasing the quantity, velocity, and transport capacity of runoff water. These preventive measures can be achieved through residue mulches or a continuous ground cover. For example, the effect of ground cover through residue mulch on different soil slopes of an alfisol in southwest Nigeria indicates that soil erosion and water runoff decrease exponentially with an increase in mulch rate. With a mulch rate of 4–6 t/ha, soil and water loss were observed to be negligible even on a slope of 15%. These basic principles for preventive measures can be applied through a range of soil and crop management practices for cassava.

Agronomic Practices for Soil and Water Conservation

(1) *Seed bed preparation:* Depending on soil type, land preparation for cassava production may involve ridges, mounds, wide beds, flat culture, or no tillage (Okigbo 1979a). In forests, the field may be either completely deforested, destumped, and burnt thereby depriving it of any cover, or all the trees may be cut but the field not destumped. In the former case, almost all permanent cover is removed; regrowth is assured in the latter. Direct impact of raindrops and tendant erosion degrades the deforested soil if it is not well managed, whereas secondary forest growth assures some cover in the selectively deforested field (Roche 1973; Vieweg and Wims 1973). The utilization of "field" preparation as contrasted with "land" preparation is an attempt to include all activities in plot preparation, which includes forest clearing and destumping, compared with activities involving land preparation such as tillage, ridging etc.

Ridges are commonly constructed in contours across slopes. If mounds are made, they are staggered to prevent the creation of straight channels for water movement. In many parts of Central Africa, the ridges are made *along* slopes, which are sometimes as steep as 60%.

Though this is recognized as a wrong practice by agronomists, farmers accept it and stick to it asserting that it assures that they do not lose all their crop, nor do the fields develop permanent gulleys. In an experiment to emulate a farmer's field on a 40% slope in an area having 1500 mm annual rainfall distributed over 5–7 months, some ridges constructed across slope were split by heavy erosion, parts were carried off, and visible erosion-paths were noted. This contrasted with ridges along slopes where less resistance was provided to erosion and the volume of water was dissipated over a larger area. Though not endorsing this practice by the Bakongo farmers of Bas-Zaire, it remains the best they have, given their level of technology. On the other hand the same practice is used in slopes of less than 5%. For soil conservation, the no-till system is the best. Comparison of the nutrient profile of an alfisol under no-tillage and conventional tillage for a 6-year period showed higher concentration of organic C, total N, available P, exchangeable K and Ca in the no-tillage system than in the plowed plot in the 0–10 cm layer (Juo and Lal 1978). Thus, the no-tillage system of cassava production as practiced in many parts of tropical Africa is an advantageous soil management system.

(2) *Live mulch:* Research on the use of live mulch to control erosion and aggressive weeds and to enrich the soil for either the present or succeeding crops is receiving a lot of attention at IITA. To be useful, the live mulch must control weeds and erosion but not compete for nutrients, light, or water with the economic crop. Yield should be comparable with that obtained from conventional methods. A number of low-growing, nonclimbing legumes and grasses have been identified (Okigbo and Lal 1977; Lal et al. 1977; Akobundu, personal communication) and extensive investigations are planned.

Farmers in Africa recognize the potential of live mulch and are practicing its use by selectively weeding their fields according to their classification of weeds. Pierson (1973) reported farmers' weed classification as: (1) those harmful to the standing crop; (2) those indifferent to present crop but helpful to the next; (3) those that grow late and that are slow and helpful to all crops.

Weeds in the first category are usually identified and removed but the others may be left. In addition to having an intercrop fallow, a farmer thus has a "live" mulch that reduces the labour required to weed his field and helps check erosion. The farmers recognize that clean weeding is not advantageous because it exposes the soil to erosion.

Growth of cassava during the first 12 weeks is generally slow and problems of weed competition are recognized as acute during that period (Akobundu 1980; Onochie 1975; Godfrey-Sam-Aggrey 1978). Many fast-growing crops mixed with cassava, such as maize, melons, and peanuts, serve as cover crops and protect the soil during periods of slow cassava growth. Competition with cassava is minimal, if any (Okigbo 1977a; IITA/PRONAM 1978).

Though considerable gaps may exist, plant spacing is usually less in farmers' fields than that recommended by researchers. At high populations, vegetative cover of the soil can be more easily attained (Akobundu 1980).

(3) *Cover crops:* Legumes that have been found suitable as cover crops include: *Calapogonium mucunoides, Centrosema pubescens, Dolichos hosei, Glycine javanica, Indigofera specata, Pueraria phaseoloides,* and *Stylosanthes gracilia* (Okigbo and Lal 1977). Cover crops may be managed in different ways. They can be turned under and used as green manure in conventional tillage systems or they can be killed with contact herbicides and used as sod in no-tillage or strip tillage systems. In Nigeria, Lal et al. (1979) reported a significant improvement in the physical and chemical characteristics of an alfisol under legume and grass cover. Both the organic matter and nutrient levels were higher under sod because of erosion control. Cassava yields were increased when a sod-mulch was used in a zero-tillage system (Lal et al. 1977; Table 1). Two grasses (*Brachiaria* and *Melinis*) and two legumes (*Pueraria* and *Stylosanthes*) contributed to excellent cassava yields. Studies of this type need to be conducted over a long period and with different soil types and ecological conditions.

Table 1. Cassava yield (t/ha) as affected by cover crops (after Lal et al. 1977).

Cover crops	Cassava root yield
Grasses	
Panicum maximum	3.50
Setaria sphacelata	7.90
Brachiaria ruziziensis	17.39
Melinia minutiflora	18.85
Legumes	
Centrosema pubescens	15.01
Pueraria phaseoloides	19.49
Glycine wightii	14.12
Stylosanthes guyanensis	19.83
Control	8.05
L.S.D. (0.05)	2.53

(4) *Conventional mulching:* Traditionally, African cassava farmers have always mulched their fields, but the extent to which the mulching is effective is questionable. Weeds are always left in the fields as mulch. Results from research conducted at IITA have conclusively shown that effective mulching results in higher cassava root yields, reduced soil erosion, and reduced weed infestation and competition. Improvements in soil physical and chemical characteristics are similar to those enumerated for sod: physical — water infiltration rate is improved, soil structure is conserved, soil microorganics are improved, and variations in soil temperature are reduced; chemical — organic matter, total N, exchangeable K, Ca, and extractable P are increased (Lal 1975, 1976), and soil acidity is reduced (Lal et al. 1977, 1979; Okigbo and Lal 1977; Juo and Lal 1978; Okigbo 1977a).

Okigbo evaluated 22 different mulching materials as they affected cassava growth and yield (Table 2). Increases in cassava yield of 40–80% were obtained using some of the mulches. Among the best in increasing root yield were black plastic (86%), rice husks (73%), cowpea, lime, and pigeon pea husks (61%), and pigeon pea and soybean tops (40% each). Most effective suppression of weed growth was achieved by rice straw, chipped cassava stem, black plastic, and maize stover. Lack of availability of mulching material is reducing the application of this most profitable and labour-reducing technique.

(5) *Shifting cultivation:* A traditional farmer, through experience, knows the limits of the productivity of his land. Shifting cultivation as practiced in Africa is an advanced soil conservation and management system that is blended with the social structure of a people. It involves cropping a land for 2–4 years and then allowing the field to regenerate into fallow for periods varying from 4 to 20 years. Due to population pressure, the period of fallow may be reduced. The farmer may shift from one field to another or he may move his homestead to virgin land (Nye and Greenland 1960).

Vieweg and Wims (1973) discussed an attempt to eliminate the usual fallow period of 10–20

Table 2. Observations on cassava grown in different mulches in 1975–76 (after Okigbo 1977a).

Treatments	Plant height at harvest (cm)	No. of roots	Fresh wt. roots (t/ha)	Dry wt. roots (t/ha)	% yield over bare
Bare — no mulch	255	4.9	16.4	10.8	100
Maize stover	331	5.6	16.4	10.8	100
Maize cobs (chipped)	330	5.1	17.8	11.8	109
Oil palm leaves	310	4.8	17.1	11.3	105
Rice straw	316	5.0	17.9	11.8	100
Rice husks	352	7.3	28.3	18.7	173
Pennisetum straw	315	4.6	14.2	9.3	86
Elephant grass	303	5.0	16.6	10.9	101
Andropogon straw	331	5.4	18.5	12.1	112
Panicum maximum	310	5.1	15.5	10.2	94
Typha straw	319	4.8	16.7	11.0	102
Cassava stems (chipped)	335	5.8	20.9	13.8	128
Pigeon pea tops	353	6.4	22.9	15.1	140
Pigeon pea stems (chipped)	333	6.3	19.9	13.2	122
Cowpea, lima, and pigeon pea husks	357	7.0	26.4	17.4	161
Soybean tops	348	6.3	22.9	15.1	140
Eupatorium	338	5.1	18.8	12.4	115
Mixed twigs (chipped)	325	5.9	18.5	12.2	113
Sawdust	344	5.3	20.5	13.5	125
Black plastic	375	8.0	30.5	20.1	186
Translucent plastic	338	7.0	27.7	18.3	169
Fine gravel	344	6.6	22.9	15.1	140
L.S.D. (0.05)	24	1.0	4.3	3.0	—

Table 3. Runoff and erosion under different soil covers in parts of West Africa (Okigbo 1977a).

Locality	Study period	Slope (%)	Mean annual rainfall (mm)	Annual runoff (%)			Erosion (t/ha)		
				Forest	Crop	Bare	Forest	Crop	Bare
Ouagadougou (Upper Volta)	1967–70	0.5	850	2.5	2–32	40–60	0.1	0.6–0.8	10–20
Safe (Senegal)	1954–68	1.2	1300	1.0	21–2	39.5	0.2	7.3	21.3
Bouaka (Ivory Coast)	1960–70	4.0	1200	0.3	0.1–26	15–30	0.1	1–26	18–30
Abidjan (Ivory Coast)	1965–70	7.0	2100	0.1	0.5–26	38	0.1	90	108–170

years in the Kilombero Valley of southeastern Tanzania. Permanent agriculture was imposed by substituting fallow with heavy N, P, K, lime, and cattle-dung fertilization. The crops used in the experiment were rice, maize, and soybean. Yields were reduced to zero after 6 years in the NPK treated plots, but liming and cattle dung in addition to NPK improved yield. Availability of cattle dung at 30 t/ha was the limiting factor. The authors concluded that shifting cultivation as practiced by the farmer was the best cropping system on the groundwater laterites of southern Tanzania. This discouraging result seems to echo the observations of Nye and Greenland (1960) as cited by Roche (1973) in which they emphasized that "after a quarter of century of experiment in the African Tropics we have failed to introduce to the forest regions any method of stable food production superior to the system of natural fallowing used in shifting cultivation."

Cassava, the last crop in almost all the cropping systems and sequences, is usually harvested from weedy plots that are at different stages of reversion into fallow. Depending on the length of fallow period, the physical and chemical characteristics of the soil are improved and soil erosion and degradation are reduced, resulting in complete regeneration and reclamation of the soil (Table 3). Crops such as yams, maize, cassava, and peanuts produce high returns when planted in the proper sequence.

(6) *Crop combination:* The practice of mixed

Table 4. Effect of cropping systems on water runoff and soil loss under cassava (Aina et al. 1977).

Slope (%)	Soil loss (t/ha/yr) Cassava	Soil loss (t/ha/yr) Cassava + Maize	Runoff (% of annual rainfall) Cassava	Runoff (% of annual rainfall) Cassava + Maize
1	3	3	18	14
5	87	50	43	33
10	125	86	20	18
15	221	137	30	19

cropping has many advantages. The continuous ground cover it provides affords protection against raindrop impact and soil splash. The effects of cassava alone and cassava and maize grown simultaneously on runoff and soil loss were compared for an alfisol in Western Nigeria (Aina et al. 1977). For the bimodal rainfall pattern at Ibadan, Nigeria, the crop management factor (c) for cassava alone ranged from 0.72 from April to August (first season) to 0.39 from August to November (second season). On the contrary, the numerical value of the c factor for the maize-cassava mix ranged from 0.43 in the first season to 0.05 in the second season. Mean soil loss was 109 and 69 t/ha/year for the monoculture of cassava and the maize-cassava mix, respectively. Similarly, the mean water runoff decreased from 28% of the rainfall in monoculture cassava to 21% in the case of maize plus cassava (Table 4). In general, soil loss and water runoff decrease exponentially with an increase in vegetative cover.

Conclusions

Although much work needs to be done on methods of soil conservation and management of cassava, the information available indicates rewarding results from mulching, minimum tillage, cover cropping and mixed cropping, population control, and selective and controlled weeding. Mulching may be limited by availability of mulching material. Shifting cultivation, although primitive and demanding of time, remains an advanced system for soil conservation in the tropical rain forest zones.

Soil-Related Intercropping Practices in Cassava Production

Carlos F. Burgos[1]

Simultaneous polyculture has been suggested as a way of reducing soil and nutrient losses and of maintaining the good physical properties of the soil. To prevent soil losses, cassava should be intercropped with a fast-growing crop that can cover the ground rapidly while the cassava develops a good leaf canopy. Soil losses for monocultures vary with soil management practices. Losses of 101–111 t/ha were measured in freshly cultivated cassava plots after a high intensity rainfall. However, maize plots that had not been cultivated for 3 months prior to the rain showed no loss.

Increases in soil resistance in nine cropping systems plots, which included cassava, appear to be related more to human traffic than any other factor.

In cassava monoculture, five times as much phosphorus was lost as was absorbed by the crop. The amount lost in two-crop polycultures ranged from two to three times as much as the amount absorbed by the plants and four-crop polycultures lost less than half the amount of phosphorus removed by the crops. Cropping systems that showed potassium loss absorbed five times as much nutrient as was lost for cassava monocrop, three times the amount lost by the two-crop intercropped, and 10 times the loss in a three-crop intercropped system.

Calcium loss appears to be greatly influenced by the degree of ground cover provided by the cropping pattern. Larger absorption than loss of magnesium from the soil was detected for two- and three-crop polyculture, and larger soil magnesium loss than absorption was observed for cassava monocrop and four-crop polyculture systems that included cassava.

There are several advantages of intercropping cassava with other crops: runoff and soil losses are reduced; the physical properties of the soil are conserved; and the maintenance of soil fertility is aided. When possible, stover of the accompanying plant should be left on, or semi-incorporated into the soil to recycle nutrients.

Intercropping is widely practiced and is common on small cassava farms in Latin America (CIAT 1976). Cassava is frequently intercropped with maize, common bean (CIAT 1975; Krantz et al. 1974; Tobon et al. 1975), yams (CATIE 1978), potatoes, tomatoes, and several other species according to traditional practices based on little-understood agronomic criteria (CIAT 1976).

Yields of cassava intercropped with either maize or common bean are sometimes similar to those of the monocrop (CIAT 1975). In other cases, when intercropped with maize and soybeans, for instance, cassava yields have been about 50% less than those of the monocrop (CIAT 1971). Cassava is commonly associated with maize in the low, humid tropics of Central America. Sometimes both crops are planted simultaneously at the beginning of the rainy season.

At CATIE (Centro Agronómico Tropical de Investigación y Enseñanza) in Turrialba, Costa Rica, several cropping systems that include cassava were studied in an experiment from 1974 to 1978. For the November planting of the 1st year, 1974–75, no significant differences were obtained for treatments that included maize. This crop, maize, competed successfully, lowering the yields of crops associated with it. Only cassava, cultivar Valencia, seemed to have made some competition for maize Tuxpeño-1, especially when they were planted simultaneously. In this case, the maize yielded 2.2 t/ha, which was significantly inferior to the maize yield in monoculture (3.2 t/ha). Cassava yield decreased by 50%, from 23.6 t/ha in monoculture to 11.6 t/ha.

From 1975 to 1976, yields of cassava and maize were evaluated in terms of dry matter. Maize yields were lower in the second planting

[1]Soil Management Specialist, Annual Crops Program, CATIE, Turrialba, Costa Rica.

(May) and showed better response to fertilizer applications in this planting, than in the first one. In the first planting, maize intercropped with cassava yielded 3524 kg/ha of dry matter, which was similar to that yielded by the monocrop. Cassava yielded 1570 kg/ha, which represented a decrease of 51% in relation to the monocrop (CATIE 1977). Between 1976 and 1977, the yield range for cassava was 6.5 t/ha at 10 months harvest to 17.3 t/ha for the monocrop harvested at 11.5 months. Yields of cassava intercropped with maize were 9.3 t/ha, which indicates strong competition caused by the maize (CATIE 1978).

From the reports available, it can be stated that the associations of cassava and other crops, mainly maize, are widely practiced in Central America and that the degree of competition between cassava and maize depends on the morphology of both crops and plant density.

Management Practices

Reduced soil and nutrient losses as well as maintenance of good physical properties have been suggested as reasons for increased yields in simultaneous intercropping.

Reduced Soil Losses

It has been proposed that, in regions of high rainfall intensity, the soil surface be kept covered for as long as possible. Cassava grown on an inceptisol of Turrialba showed highest increments of total biomass between 4 and 8 months after planting (Gallegos 1976). Cassava in monoculture reached its peak of leaf area production before any of the five cropping systems under study, namely:[2] cassava → sweet potato → sweet potato; cassava → maize → maize; cassava + common bean → maize; and cassava + common bean + maize → sweet potato; however, it shed leaves sooner than in the other systems.

The highest leaf area index measured for cassava was 1.44 for the monocrop at age 6 months and 1.51 at 8 months for cassava + common bean intercropping (Gallegos 1976). These values are low when compared with values obtained elsewhere: Colombia 2.0; Nigeria 5.6 and 7.5. Experimental results reported of leaf area index curves and reserve roots (Gallegos 1976) showed for cassava monoculture a progressive leaf area increase up to age 6 months when the leaf area began to diminish. However, the biomass of the roots increased rapidly, starting at the 6th month. Therefore, as a protection against soil losses, cassava should be simultaneously intercropped with a fast-growing crop that can cover the ground rapidly. The intercropped plant should be harvested when the cassava canopy and roots provide protection against erosion of the soil.

In a forest receiving 2000 mm rainfall per year, annual soil losses of 900 kg/ha have been reported from small plots with slopes of 2–15%. A plot of 7–8% slope under bare fallow lost 100 t/ha-year (Greenland and Nye). On moderate slopes planted very closely, soil losses may not be so important. It has been reported (Greenland and Nye) that plots with a 25% slope, which had been cleared in a forest with a rainfall of about 2500 mm a year and planted to upland rice with little disturbance of the soil, lost 4050 kg/ha in the 1st year and less than 900 kg in the second.

Mounding or ridging of the soil for root crops such as yams, sweet potato, and cassava accelerates erosion in forest environments (Greenland and Nye). Rotation experiments (2 years of rice followed by sweet potato on ridges or by cassava planted on the flat) showed a loss of 4 t/ha from the ridged plot but only small losses from the undisturbed plot. Soil losses vary in magnitude depending on rainfall intensity, percent of slope, soil type, and soil and crop management. Amounts of soil losses range from 2.7 to 4.9 t/ha a year (Greenland and Nye). Traditional systems used by small farmers in forest regions seem to protect the soil well from erosion even on steep slopes and under heavy rainfall.

Soil erosion problems have also been studied in Nigeria (Lal 1976) for different soil management practices and four cropping systems: maize → maize with mulch; maize → maize with tillage; maize → cowpea with no tillage; and cowpea → maize tilled. The study was carried out on an alfisol; average rainfall was 1100–1300 mm bimodally distributed. Soil losses for a 10% slope were: bare fallow 153 t/ha; maize → maize with mulch 0.1 t/ha; maize → maize tilled 4.4 t/ha; maize → cowpea untilled 0.1 t/ha; and cowpea → maize tilled 3.3 t/ha. The same trend was found for 1.5 and 15% slopes (Lal 1976). These results show that mulching and no tillage treatments are very effective in preventing soil losses on land with slopes ranging from 1 to 15%.

Crops and soil management systems that provided early ground cover controlled runoff and erosion better than those that did not (Lal 1977). The number of days required for 50%

[2]The symbol → means rotation; + means association.

canopy to form was approximately 38, 48, and 63 for respective cultivars of soybeans, pigeon peas, and cassava grown at Ibadan, Nigeria (Lal 1977).

Soil-conserving crops are those with quick growth; soil-depleting crops take longer to cover the ground. Practices such as mixed cropping also affect ground cover. It took cassava as a monocrop 63 days to cover 50% of the ground, whereas intercropped maize and cassava took only 51 days (Lal 1977).

Soil erosion and runoff losses were less with mixed crops than with monocrops in an alfisol in Nigeria (Lal 1977). Other cultural practices that affect erosion control are plant density, planting time, and soil fertility. More important than the growth habit is the soil management practice. Soil-depleting crops grown with proper soil-conserving techniques could result in less runoff and soil losses than a soil-conserving crop grown without conservation practices (Lal 1977). This was the case when maize (considered a soil-depleting crop) was grown in untilled plots and compared with cowpea (soil-conserving crop) grown with no conservation practices. Runoff and soil losses were less for maize than for cowpea, especially on slopes greater than 5% (Lal 1977).

Soil losses for rotations in tropical regions of Africa and Madagascar have also been studied (CIDIAT 1977). Rotations that included cassava showed higher soil losses and mean annual runoff. This finding was probably due to cassava's delay in developing an effective ground cover. Soil losses in the system peanuts → green manure cowpea → cassava → forages (soybeans + maize) were higher, 15.80 t/ha-year, in unfertilized plots than plots receiving manure plus potash, which lost 11.73 t/ha-year. Plots that received potash alone had a slightly lower soil loss (15.67 t/ha-year). Soil losses for cassava in the 1st year were 19.60 t/ha and in the 2nd year, 17.46 t/ha. These losses were less appreciable on plots fertilized with manure and potash, namely: the 1st year 15.28 t/ha, and the 2nd year, 2.90 t/ha (CIDIAT 1977).

At Turrialba on 6 December 1949, a heavy rain fell (410 mm, of which about 250 mm fell in fewer than 10 h) on plots utilized for studies of soil and water runoff from grass, bare soil, and rotation of molasses grass, tropical kudzu, potatoes, peanuts, grain sorghum, and cassava. Soil losses from plots planted with cassava were 101 and 111 t/ha for the 16 and 45% sloped plots, respectively. Plots covered with grass showed zero loss. The high losses reported for cassava plots were due to the early growth stage of cassava and to the fact that they had been freshly cultivated just before the storm (Ives 1951). Plots covered with corn had not been touched since September, and crops and weeds provided a good cover for the ground. No soil losses were observed from these plots. These results give support to the suggestion that intercropping and mixed cropping reduce soil losses and in this way help to maintain the soil in good condition; in addition they sometimes increase yields.

Table 1. Calculated soil losses for cassava monocrop grown in two soil series of Turrialba (ultisol-inceptisol CATIE 1975).

Slope (%)	Length (m)	Soil series	Soil loss (t/ha-year)
5	15	Colorado	1.61
5	30	Colorado	3.21
10	30	Colorado	5.97
5	15	Instituto	2.42
5	30	Instituto	4.83
10	30	Instituto	8.98

Soil losses in cassava monoculture were calculated by the Universal Soil Loss Equation in two soil series, Colorado and Instituto, at CATIE, Turrialba, Costa Rica (Table 1). The data indicate rather low soil losses, mainly due to the low-intensity rains in Turrialba.

Physical Properties

The effect of various cropping systems on the mechanical resistance of soils was studied at CATIE, and in a complementary study (Tafur 1976). Criteria for interpreting resistance to penetration were 0–6 bars, excellent; 7–12 bars, acceptable; 13–25 bars, unacceptable; 25 and higher restricts root growth. Variations measured for all 48 treatments, 24 cropping systems at two levels of technology, were not significant. Values obtained ranged from 13.64 to 8.74 bars. At the time of measurement, correspondence between resistance and number of crops grown on the soil was not detected. Lowest resistance values were found on the soil surface, 6.46 bars; at 30 cm deep, values increased significantly to 13.20 bars. When the common beans were harvested, resistance to penetration values (adjusted to 40% of soil moisture) were, on average, higher for plots not intercropped with cassava than on those that were. Plots that included maize without cassava gave lower resistance readings, 16.4 bars, than those intercropped with cassava, 17.78 bars. Subtracting the resistance just before harvesting from the resistance before the experiment was started suggested that increase of soil resistance to penetration is more related to human traffic than any other activity (Tafur 1976).

On the soil surface, soil resistance adjusted to 40% soil moisture increased from 4.2 to 8.8 bars after 10 months of cropping; at 10 cm depth, the changes of adjusted resistance were very small; at a depth of 20–30 cm, variations of the resistance depended greatly on soil moisture changes, whereas on the soil surface the changes were attributed to human traffic (Tafur 1976).

Compared with bare and covered soils, sweet potato intercropped with cassava and maize significantly increased the adjusted resistance from the surface to 20-cm depth. On plots planted with maize, a large part of the area was walked or stepped on twice, whereas on plots with sweet potato intercropped with cassava the entire area was stepped on twice and in some places three times (Tafur 1976).

The soil with cassava and sweet potato simultaneously intercropped had an air space of 8.1%; the value for maize monocrop was 10.8%. This difference was not significant. The lower average aeration of the intercropped plot was probably due to compaction caused by human traffic.

The effect of ridging or hilling on the performance of cassava intercropped with maize, string bean plus maize, and string beans was assessed at CATIE (Gerodetti and Holle 1980). At the beginning of the experiment, bulk density was 0.75 g/cm^3 on the ridge and 0.89 g/cm^3 on flat soil. At harvest, average bulk density was 0.86 g/cm^3 for both, the differences between soil management systems having disappeared.

Soil resistance to penetration was 2.15 bars for the flat soil and 1.12 bars for the ridged soil; both values are within the 0–6 range considered excellent. At harvest, the values were 5.27 bars for flat and 2.92 for ridged soil; this difference was significant ($p = 0.01$), although they were both still within the range of values considered excellent for root penetration and development. The soil from which cassava was harvested was moist, and manual harvest was not difficult.

Cassava planted on flat soil yielded more total roots (24.8 t/ha for monoculture; 14.4 t/ha for intercropped plots) and commercial roots (17 t/ha and 9 t/ha, respectively) than did the cassava on ridged soil where average yields of total roots for cassava monoculture and intercropped maize–cassava were 21.6 and 12.4 t/ha, respectively. Commercial root yields on ridged soil were 12.3 and 6.2 t/ha for cassava monocrop and intercropped maize–cassava, respectively. For both cassava monocrop and cassava–maize planted on flat soil, more roots of commercial quality were obtained in relation to yields on ridged soil. No differences were found among management systems, flat and ridged land, for number of total and noncommercial roots.

More broken roots were obtained from flat than from ridged plots: average 9.4 roots per plot compared with 5.9 for the ridged soil. The area harvested for each plot was 30 m^2. Planting without ridging increased cassava and bean yields, but maize yields were similar for flat and ridged plots (Gerodetti and Holle 1980).

Nutrient Losses

The reduction of nutrient losses has been proposed as one of the reasons for increased yeilds from intercropped plots. However, reduced soil losses may not affect yields of crops in the same growing season, but will conserve soil fertility in the long run. There are few studies that measure the effects of intercropping on soil nutrients (Kass 1976).

The cropping system did not have a significant effect on the exchangeable Ca, Mg, or K content in soil where maize and pigeon peas had been planted (16 weeks before) in monoculture and intercropped plots. This study was carried out in soil with an exchange capacity of 12 meq/100 g and in an environment with monthly rainfall less than 10 mm; under these circumstances leaching of nutrients would probably be small (Kass 1976). Sandy soils (dystrophic red and yellow quartz sands) of the Tracuateua Experiment Station (UEPAE), Pará, Brazil, where rainfall for 8 months was more than 100 mm but less for the remainder of the year, lost about five times as much magnesium, 85 kg/ha, as was recovered in the plants, 18 kg/ha, in cassava monoculture, cassava + maize, and cassava + maize + rice plots. About four times as much was lost, 58 kg/ha, in the rice → cowpea sequence, and less than three times, 33 kg/ha, as much in the rice + cassava combination (Kass 1976). These findings indicated that losses of magnesium at a depth of 0–40 cm were considerably less for simultaneous intercropping of rice and cassava than for the other cropping systems tested. A similar but less marked pattern was observed for potassium. Potassium soil losses were 113, 100, 112, 103, and 143 kg/ha for cassava monocrop; rice → cowpeas; cassava + maize; cassava + rice; and cassava + maize mixed cropped with rice, respectively.

In experiments with polycultures at CATIE, Turrialba, it was found that cassava had higher nutrient uptake when intercropped than when grown alone. Intercropped with maize, cassava had a total nutrient uptake of 417, 51, and 357 kg/ha of N, P, and K, respectively. These amounts were higher than the amounts added as chemical fertilizer (Jimenez 1976). This study suggests that cassava as a monocrop absorbs larger amounts of K and N than of any other nutrient.

At CATIE (Soria et al. 1975), several cropping systems that included maize, beans, sweet potato, and cassava were studied. The spatial and chronological arrangements that were tested consisted of association, sequences, and relay of crops. In some cases, the cropping systems were managed at two levels of fertilizer application.

Nutrient Changes

Studies were conducted at CATIE in an inceptisol from 1974 to 1978 to ascertain nutrient changes in the soil with systems that included cassava. The nutrients measured were phosphorus, calcium, potassium, and magnesium.

Extractable P in the soil where cassava was grown alone had a marked decline in 1975, but it increased in 1976 to a level higher than its initial value. At harvest in 1978, P was 1 ppm higher than the 1974 level. The same pattern was observed for polycultures such as cassava + green maize; cassava + maize; cassava + maize → green maize; cassava + sweet potato; and cassava + maize + beans → sweet potato. The cropping system of beans intercropped with maize gave lower values than cassava monoculture.

Exchangeable potassium in the 0–30 cm soil layer of the cassava monoculture decreased during the experimental period from 0.29 to 0.22 meq/100 g. The cassava monoculture to which a higher dose of fertilizer was applied had a larger decrease in the soil exchangeable potassium (0.29 to 0.14 meq/100 g). A decrease in the level of exchangeable potassium was the trend in every system.

Soil exchangeable magnesium diminished with time for all systems, but a sharper decline was measured for the more intensive systems.

In 1976 a marked drop of the calcium level was also observed for most treatments, but for 1978 calcium levels increased to about the level of 1974. The mechanisms that may explain this phenomenon are excessive leaching in 1974 and 1975 and calcium removal by both cassava and the accompanying crop. In 1978, the calcium level measured was higher than expected, probably because the soil-extracting solution employed (ammonium acetate pH 7.0) was different from the one used previously.

Nutrient Balance Sheet

Table 2 indicates that phosphorus losses were highest for the cassava monocrop system. The other systems in descending order with regard to phosphorus losses were simultaneous intercropping of cassava plus beans (T 52 B+C); beans + cassava followed by green maize (T 16-2 B+C→Me), fertilized at a higher dose than T 16-1 (B+C→Me); maize + cassava (T 6-2 M+C); beans + cassava followed by maize (T 16-1 B+C → Me); beans + maize + cassava followed by sweet potatoes (24-2 B+M+C+→SP), fertilized with a high dose of fertilizer; and, in last place, beans + maize + cassava followed by sweet potatoes (24-1 B+M+C+→SP). It is evident that soil phosphorus losses were less in systems that included maize and much less in three-crop polycultures. Another interesting fact is that phosphorus removal by aerial parts of cassava was higher in four-crop polycultures than in two- or three-crop intercropping. Phosphorus loss was influenced

Table 2. Phosphorus balance sheet for five selected cassava intercropped systems tested on an inceptisol at CATIE (1975–78).

System[a]	Applied P (kg/ha)	Soil P (kg/ha)		Plant P uptake[b] (kg/ha)			Loss of P from soil (kg/ha)	Loss of P from system (kg/ha)
		Start	End	S+L	R	Acc		
1-2 C	128	6	12	15	4	—	–6	103
6-2 M+C	128	4	6	15	2	32	–2	77
5-2 B+C	128	4	8	13	4	13	–4	94
16-1 B+C→Me	99	8	16	13	3	34	–8	41
16-2 B+C→Me	139	6	6	12	4	37	0	86
24-1 B+M+C+→SP	99	6	8	18	2	60	–2	17
24-2 B+M+C+→SP	139	4	12	22	2	66	–8	41

[a]C = cassava; B = beans; SP = sweet potato; Me = green maize; M = maize; → = double cropping; + = association of crops; +→ = double cropping of crop association.

[b]S+L = stem plus leaves; R = roots; Acc = accompanying crop.

Table 3. Potassium balance sheet for five selected cassava intercropped systems tested on an inceptisol at CATIE (1975–78).

System[a]	Applied K (kg/ha)	Soil K (kg/ha)		Plant K uptake[b] (kg/ha)			Loss of K from soil (kg/ha)	Loss of K from system (kg/ha)
				S+L	R	Acc		
1-2 C	166	140	109	96	68	—	31	33
6-2 M+C	311	109	109	62	39	246	0	No loss
5-2 B+C	311	117	94	56	59	143	23	76
16-1 B+C→Me	187	109	117	55	51	277	–8	No loss
16-2 B+C→Me	336	140	101	52	57	311	39	45
24-1 B+M+C+→SP	166	101	125	78	34	450	–24	No loss
24-2 B+M+C+→SP	332	101	86	129	29	521	15	No loss

[a]C = cassava; M = maize; B = beans; Me = green maize; SP = sweet potato; → = double cropping; + = association of crops; and +→ = double cropping of crop association.

[b]S+L = stem plus leaves; R = roots; and Acc = accompanying crop.

Table 4. Calcium balance sheet of five selected cassava intercropped systems tested on an inceptisol at CATIE (1975–78).

System[a]	Soil Ca (kg/ha)		Plant Ca uptake[b] (kg/ha)			Loss of Ca from soil (kg/ha)	Loss of Ca from system (kg/ha)
	Initial	Final	S+L	R	Acc		
1-2 C	2080	2040	120	12	—	40	–92 No loss
6-2 M+C	2160	1760	99	7	84	400	210
5-2 B+C	2160	2000	92	10	301	160	–243 No loss
16-1 B+C→Me	2400	1920	94	9	165	480	212
16-2 B+C→Me	1520	2000	81	10	180	–480	–209 No loss
24-1 B+M+C+→SP	2160	2200	107	7	81	– 40	–235 No loss
24-2 B+M+C+→SP	2240	1960	129	9	82	280	60

[a]C = cassava; B = beans; SP = sweet potato; Me = green maize; M = maize; → = double cropping; + = association of crops; and +→ = double cropping of crop association.

[2]S+L = stem plus leaves; R = roots; and Acc = accompanying crop.

more by the number of crops in the system than by the rate of phosphorus application.

The potassium balance sheet (Table 3) shows that potassium losses did not occur from systems that contained maize harvested for grain, regardless of the amount of applied potassium. Also, no loss was detected for the cropping system that included maize to be harvested as green corn and received a relative low application of potassium in the form of chemical fertilizer. Table 3 indicates that cassava in monoculture removes higher amounts of potassium from the soil than when associated with one, two, or three crops. However, at a high rate of fertilization and in association with three other crops, one of which is maize to be harvested for grain, cassava is responsible for higher potassium removal than when it is grown alone.

In general terms, the calculations presented in Table 2 show that in cassava monoculture five times as much phosphorus is lost than is absorbed by the crop. However, the amount lost in two-crop polycultures ranged from two to three times as much as the amount absorbed by the plants, and soils in four-crop polycultures lost less than half the amount of phosphorus removed by the crops.

In the case of potassium, cropping systems that showed some loss absorbed five times as much nutrient as was lost for the cassava monocrop system, three times the amount lost by the two-crop intercropped, and 10 times the losses in a three-crop intercropped system.

Calcium losses (kg/ha) in three systems namely, maize associated with cassava (M+C), beans associated with cassava followed by green maize (B+C→Me), and beans associated with maize and cassava followed by sweet potato (B+M+C+→SP), were 210, 212, and 60, respectively (Table 4). Calcium losses for maize plus cassava (M+C) were higher than for cassava monoculture perhaps because of the reduced

Table 5. Magnesium balance sheet of five selected cassava intercropped systems tested on an inceptisol at CATIE (1975–78).

System[a]	Applied Mg (kg/ha)	Soil Mg (kg/ha) Initial	Soil Mg (kg/ha) Final	Plant Mg uptake[b] (kg/ha) S+L	R	Acc	Loss of Mg from soil (kg/ha)	Loss of Mg from system (kg/ha)
1-2 C	47	384	312	44	6	—	72	69
6-2 M+C	50	312	288	41	3	58	24	−28 No loss
5-2 B+C	50	384	312	40	5	59	72	18
16-1 B+C→Me	11	384	336	33	4	46	48	−24 No loss
16-2 B+C→Me	47	312	336	35	5	54	−24	−71 No loss
24-1 B+M+C+→SP	11	456	192	38	3	32	264	202
24-2 B+M+C+→SP	47	384	192	48	4	33	192	154

[a]C = cassava; B = beans; SP = sweet potato; Me = green maize; M = maize; → = double cropping; + = association of crops; and +→ = double cropping of crop association.

[b]S+L = stem plus leaves; R = roots; and Acc = accompanying crop.

ground cover provided by bent corn stalks. This system (6-2 M+C) received a rate of fertilizer application (Table 3) that resulted in a vigorous corn growth and a slow growth of cassava in competition with maize. The amounts of calcium removed from the soil when cassava was planted in monoculture were similar to those removed when it was associated with one, two, or three crops, regardless of the fertilization rate employed. It appears that calcium loss from the system was greatly influenced by the ground cover provided by the cropping patterns.

Magnesium absorbed by cassava monoculture was about half the amount taken up by two-, three-, and four-crop systems (Table 5). Magnesium losses detected for cassava monoculture, cassava associated with beans, and for two four-crop polycultural systems were 72, 72, 264, and 192 kg/ha, respectively. As in the case of calcium, it appears that magnesium loss is greater in systems that do not cover the soil properly. In the four-crop polycultures, the chronological sequence of harvesting and the establishment of the last crop (sweet potato) influenced the magnesium losses from the soil. In general, plants in two- and three-crop polycultures had larger absorption of magnesium than was lost from the soil, whereas the four-crop polycultures and cassava as a monocrop had larger soil magnesium losses than absorption.

All things considered, the advantages of intercropping cassava with other crops are many: it reduces runoff and soil losses, helps to conserve good soil physical properties, and helps maintain soil fertility. When possible, stover of the accompanying plants should be left on, or semi-incorporated into the soil, so that nutrients are recycled in the system.

Future Research

Studies on the performance of cassava in intercropping systems and the effects of various environments deserve attention because of the possibilities presented by these systems for the recycling of soil nutrients. More information is also needed about soil losses in various situations of rainfall intensity, slope, and coverage by plant canopy. The role of weeds in the protection of soil against soil and nutrient losses should also be studied as should the effect of cassava intercropping systems on the physical properties of the soil, especially soil compaction caused by excessive human traffic, which is closely related to the amount of care required by the plant intercropped with cassava. Human traffic causes changes of the physical properties of the soil depending on ground cover and soil moisture content.

Long-Term Fertility Considerations in Cassava Production

S.K. Chan[1]

This paper presents the results of studies on (1) effects of repeated cropping with cassava under different fertility conditions on yields; soil pH; and nutrient status of the soil and of the plant, including nutrient removal by cassava; and (2) effects of manurial history on root yield. It is concluded that soil fertility would decrease under successive cropping with cassava if the rate of fertilizer application was just enough to maintain yield.

It is often said that cassava is very exhausting to the soil. The statement is readily acceptable if there is no attempt to replenish the soil with what has been removed by the crop; for all crop species grown in the same way, harvest would impoverish the soil sooner or later. But cassava being a hardy plant is made notorious for this, because in the past it was often used by growers to exploit the soil without fertilizer input for short-term gain.

Nevertheless, published figures on nutrient uptake do indicate that cassava removes considerably large quantities of nutrients at harvest, particularly potassium. Greenstreet and Lambourne (1933) reported that cassava with root yields of 28–30 t/ha consumed, in metric equivalents per ha, 114–209 kg of N, 25–37 kg of P_2O_5, and 240–335 kg of K_2O. Hendershott et al. (1972) gave the average nutrient removal per hectare by 14-month cassava producing 59 t of roots as 106 kg of N, 47 kg of P (108 kg as P_2O_5), 467 kg of K (563 kg as K_2O), 145 kg of Ca (203 kg as CaO), and 45 kg of Mg (75 kg as MgO).

With cassava grown as a monocrop, Greenstreet and Lambourne (1933) presented results from three cropping seasons showing increased yield with fertilization and no signs of decline in yield. With cassava grown in rotation with other crops, Ofori (1973) reported important responses to K throughout the cropping period and to P in the earlier years of cropping when it was grown in rotation with maize and groundnuts for 19 years without indications of decrease in yield.

The important question remains: Do the present cultivars and cultural practices of cassava tend to create poorer soil conditions and the need for increasing fertilizer application? This paper reports the effects of repeated cropping of cassava under different fertility conditions on yields, soil pH, nutrient composition of both soil and plant, and nutrient removal by cassava. It is hoped that the results of these studies will increase awareness of the importance of maintaining soil fertility in cassava production and promote greater research efforts in the development of new varieties and cultural practices that require less fertilizer to produce the same yield of roots.

Materials and Methods

Experiment (a)

The design of this experiment was a factorial NPK 3^3 with two replicates. Each replicate had 27 treatments allocated to three incomplete blocks each containing 9 treatments, thus partially confounding the second order interactions. The three major nutrients, N, P, and K, were factorially combined with three rates of nutrient application as follows: level 0 no fertilizer; level 1 56 kg/ha N, 34 kg/ha P (as P_2O_5), 76 kg/ha K (as K_2O); level 2 112 kg/ha N, 68 kg/ha P (as P_2O_5), 156 kg/ha K (as K_2O). For the eighth and ninth crops, the rates of K application were

[1]Agronomist, MARDI, Serdang, Malaysia.

raised at level 1 from 78 kg to 156 kg of K_2O and at level 2 from 156 kg to 312 kg of K_2O.

The forms of N, P, and K fertilizers were sulfate of ammonia, triple superphosphate, and muriate of potash, respectively. Plots, including border rows, were 3.7 × 14.6 m and contained 4 rows of plants with 16 plants per row at a planting distance of 0.9 × 0.9 m. Experimental data were obtained from the inner two rows, which consisted of 20 plants in each plot.

In the ninth cropping season, Mg was incorporated as an additional treatment such that half of each plot with the original treatment received Mg and the other half did not. The rate of application was 50 kg MgO/ha. The Mg fertilizer was kieserite.

The trial was laid down on a colluvial soil at Serdang, previously planted with groundnuts, soybeans, and sweet potatoes. After the last crop of sweet potato, the land was used for the long-term fertility trial with cassava, cv. Black Twig. The land was plowed, harrowed, and rotovated before planting. Stakes (23 cm long) were planted horizontally approximately 5 cm beneath the soil.

For the first planting, stakes were obtained from cv. Black Twig grown in another plot of land. Because of a shortage of Black Twig planting materials, two other cultivars were used as border plants, cv. Green Twig for Replicate I and cv. Ubi Putih for Replicate II. In all subsequent plantings only Black Twig was used. Beginning with the third crop, well-grown border plants were selected as planting material and randomly distributed to the plots.

Fertilizers were applied about 3 weeks after planting. Before fertilization, soil samples in each plot were taken to a depth of 23 cm near the planted stakes. However, results of analyses were available only from samples taken at the sixth, seventh, eighth, and ninth seasons of planting.

Manual weeding with a *cangkol* was usually carried out twice within the first 6 months after planting. Sometimes, about a month before harvesting, weeds were sprayed with paraquat to facilitate harvesting.

During the growing period, beginning with the third crop onwards, leaf samples for chemical analyses were taken from the experimental plants at the sixth leaf position 3 months after planting.

At harvest, the fresh weight of roots was recorded from every plot. For the first crop at harvest, samples of leaves, leaf stalks, whole stems, and roots were analyzed for N, P, K, Ca, and Mg. Results of these analyses were used to estimate quantities of nutrients taken up by Black Twig on 1 ha of land. The quantity of a nutrient consumed by a plant component was estimated as a product of the dry weight of the plant component and its content of the nutrient on a dry-weight basis. For the seventh, eighth, and ninth crops, 5-cm sections of stems were taken at 50 cm above ground level and analyzed for N, P, K, Ca, and Mg on a dry-weight basis.

In the soil, available P was determined by Bray and Kurtz No. 1 method; exchangeable K, Ca, and Mg were extracted with 0.5 *N* ammonium acetate solution, and water-soluble K was determined with distilled water. For measuring soil pH, distilled water was also used. Organic carbon content of the soil at planting of the third and fifth crops was determined by the Walkley-Black Method.

For foliar analyses, standard procedures were used in determining total N, P, K, Ca, and Mg, expressed as a percentage of dry weight of the leaf.

Experiment (b)

Eight types of stakes were obtained from the eighth crop in Rep. I of Expt. (a), which had the following different fertilizer treatments: $N_0P_0K_0$ (control) no nutrients applied; $N_2P_0K_0$ only N applied at 112 kg N/ha as sulfate of ammonia; $N_0P_2K_0$ only P applied at 68 kg P_2O_5/ha as triple superphosphate; $N_0P_0K_2$ only K applied at 312 kg K_2O/ha as muriate of potash; $N_2P_2K_0$ both N and P applied; $N_2P_0K_2$ both N and K applied; $N_0P_2K_2$ both P and K applied; and $N_2P_2K_2$ all N, P, and K applied.

The eight types of stakes were tested in two separate experiments at the same location, i.e. Expt. (i) without basal dressing of NPK mixture and Expt. (ii) with basal dressing of NPK mixture consisting of 60 kg N, 30 kg P_2O_5, and 120 kg K_2O/ha. In both experiments, the stakes were planted in three complete randomized blocks. The 23-cm stakes were placed horizontally to a depth of 3 cm under the soil and at a planting distance of 1 × 1 m. Plot size including border plants was 4 × 12 m. Harvested plot size was 2 × 10 m, giving 20 harvested plants per plot.

The trial was conducted on a colluvial soil at Serdang, Selangor. Before planting, the land was plowed, harrowed, and rotovated. Just after planting, a preemergence herbicide, Fluorometuron, was sprayed uniformly on the plots.

The plants were harvested after 6 months in the field. In each plot the fresh weight of roots was recorded. Residual effects in the stakes on the yield of roots were analyzed by applying Yate's method.

Results and Discussion

Experiment (a)

Rainfall Distribution During Cropping Periods

Table 1 shows the rainfall distribution at quarterly periods for a total period of 360 days from the time of planting of each crop. In the fifth cropping season, there was a dry spell when the crop was 3–6 months old. In the eighth cropping season, there was another dry spell when the crop was 9–12 months old. These dry spells could account for low-yield performance.

Ages of Crops at Harvest and Fallow Periods

Ages of crops estimated from the time of planting to harvesting and fallow periods between two consecutive crops are shown in Table 2.

As seen from Table 2, the third crop had a longer growing period and a much longer fallow period before planting compared to other crops. The second crop also had a relatively long fallow period of nearly 6 months before it was planted. These differences in age and fallow period should be considered in comparing the yields of the various crops.

Yields of Roots as Affected by Potassium

The yields of the nine crops at three levels of potassium application are shown in Fig. 1. At the K_0 level, the root yields from the highest to the lowest did not correspond to the same order of successive crops from the first to the ninth. Instead of being the highest in yield, the first crop at K_0 had the same yield as the sixth crop. This was due to the adverse competition caused to Black Twig by the more vigorous varieties used as border rows during the first season of planting. The yield of the second crop was exceeded by that of the third. The very long fallow period of 1 year and a growing period of 14 months could be the reasons for the excellent yield performance of the third crop. The yield of the fifth crop was exceeded by the yields of the sixth and seventh crops, apparently because there was a very dry period (Table 1) during the fifth cropping season. For the same reason, the yield of the eighth crop was exceeded by that of the ninth crop.

Except for the first crop, the yields of all the other crops were markedly increased by the application of potassium. From the first to the seventh crops, the highest level of K applied to each crop was 156 kg K_2O/ha. Even at this rate of application, the yield of the seventh crop appeared to decline in comparison with earlier crops not affected by dry period. Hence, the higher rates of K application at 78 kg and 156 kg K_2O/ha were doubled for testing in the eighth and ninth cropping seasons keeping the K_0 rate unaltered. At 312 kg K_2O/ha, the yield of the ninth crop exceeded that of the seventh crop, which was fertilized at 156 kg K_2O/ha. A similar performance was not shown by the eighth crop for the reason already given.

Table 1. Rainfall distribution for four 90-day periods following planting.

	Rainfall (mm) for periods of 90 days			
Crop	1st	2nd	3rd	4th
1st	604	577	523	686
2nd	555	901	507	571
3rd	581	472	377	694
4th	852	713	560	649
5th	299	78	437	408
6th	301	333	226	639
7th	699	754	347	558
8th	634	602	455	130
9th	335	533	694	590

Table 2. Age of crops at harvest (months), and fallow periods (months) between consecutive crops.

Crop	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Fallow		5.75	12	4	2.5	1.5	1.5	1	1.5
Age	12	12	14	12	12	12	12	12	12

Yields of Roots as Affected by Nitrogen and Phosphorus

The responses in fresh root yield to nitrogen and phosphorus were different in the two replicates. In Rep. I, Fig. 2, the seventh, eighth, and ninth crops consistently showed that root yield was increased by application of P in the absence of N. However, applying P at the highest level of N application resulted in yield decrease. Good yields were obtained by applying N at the highest level without P, by applying P at the highest level without N, or by application of both N and P at intermediate levels, i.e. 56 kg N and 34 kg P_2O_5/ha.

In Rep. II, NP interaction occurred in the opposite way, as shown in Fig. 3. Without N application, fertilizing with P decreased fresh-root yield. Similarly, without P application, fertilizing with N reduced yield. The adverse effect of one fertilizer applied at the highest rate

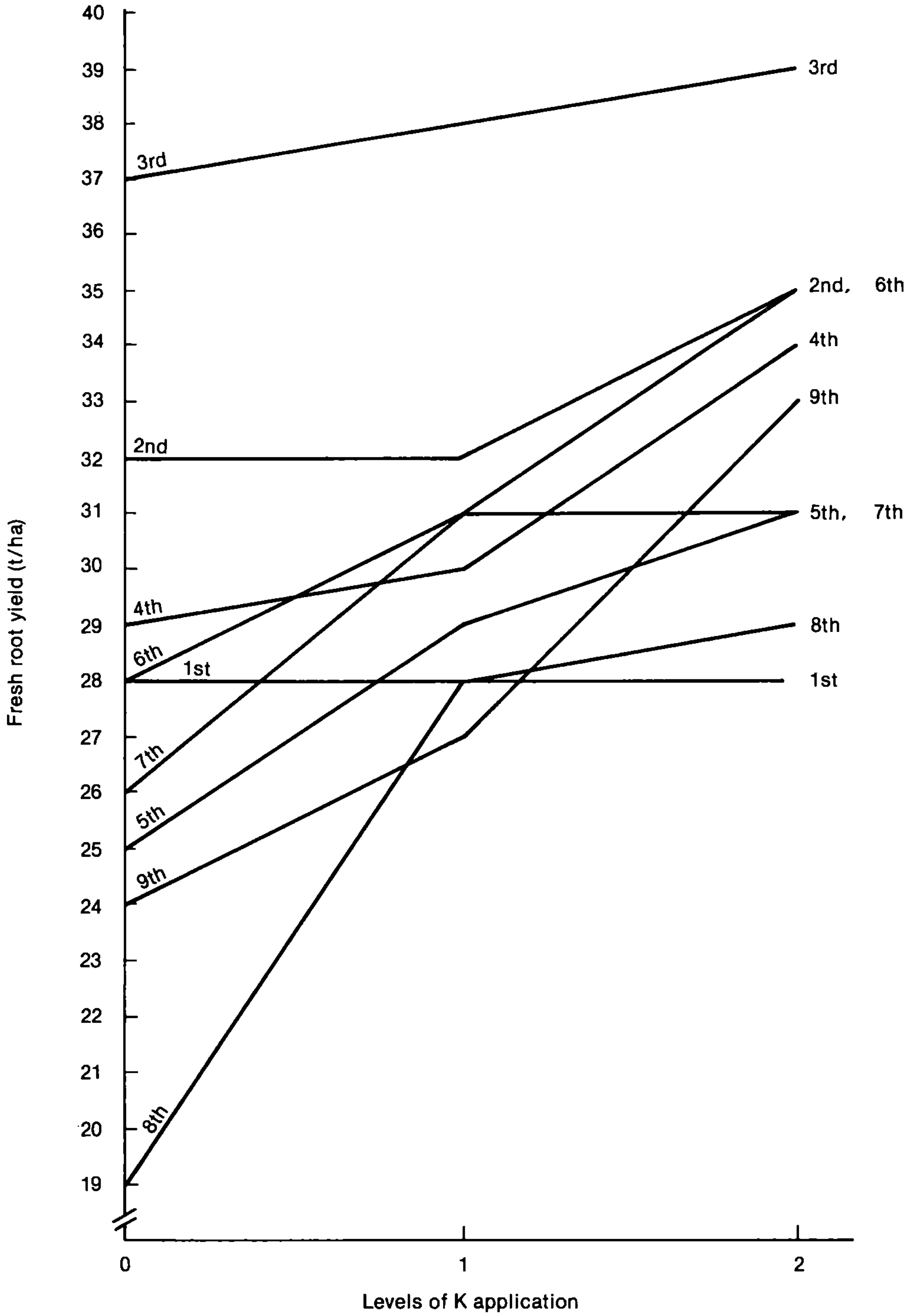

Fig. 1. Root yields of successive crops as affected by levels of potassium application. (Rates of K application were doubled at K_1 and K_2 for the eighth and ninth crops.)

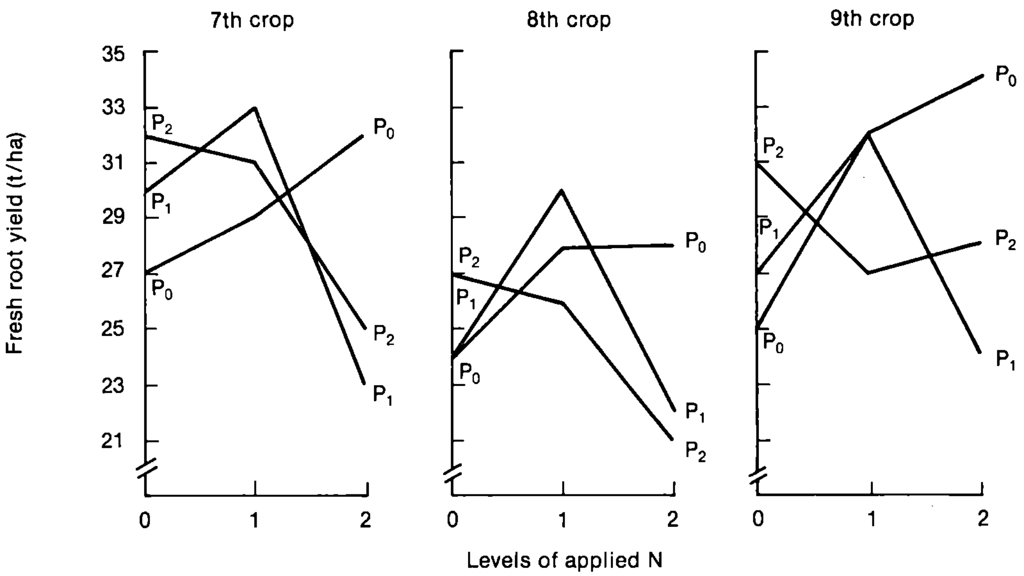

Fig. 2. Root yields of the seventh, eighth, and ninth crops in Rep. I as affected by N and P fertilization.

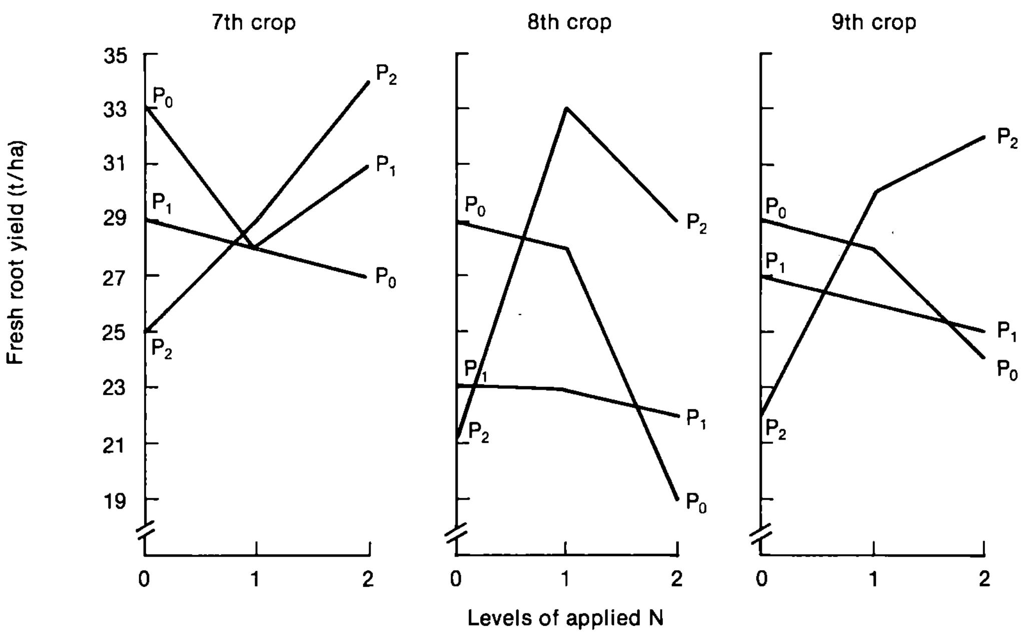

Fig. 3. Root yields of seventh, eighth, and ninth crops in Rep. II as affected by N and P fertilization.

was greatly reduced by adding the other at the highest rate.

The causes of these NP interactions have not been identified, but their repeated occurrences deserve a more thorough investigation. Unless these interactions are properly understood, the haphazard application of N and P could lead to any of the three results: more yield, no change in yield, or even less yield.

Yields of Roots as Affected by Magnesium

Symptoms of magnesium deficiency were observed on the leaves of the eighth crop in Rep. II, but not in Rep. I. When these symptoms first occurred is not known. In planting the ninth crop, Mg was included as an additional treatment. Results of statistical analysis show that the mean fresh-root yield was increased by Mg treatment in Rep. II (from 30 to 35 t/ha), but there was no significant difference due to this treatment in Rep. I. It is also noted that the soil in Rep. II (9 ppm) contained less Mg than that in Rep. I (11 ppm).

Table 3. Fresh-root yield (t/ha) of treatments giving more than 40 t/ha per cropping season.

	Rep. I			Rep. II	
Crop	$N_1P_1K_2$	$N_1P_0K_2$	$N_0P_2K_2$	$N_1P_2K_2$	$N_1P_0K_2$
1st	34	36	32	37	38
2nd	55	41	35	34	41
3rd	47	54	49	46	52
4th	40	49	43	48	44
5th	34	46	36	39	39
6th	39	46	50	61	42
7th	47	30	38	43	40
8th	51	40	39	46	29
9th	49	38	44	41	41
Mean	44	42	41	44	41

NOTE: The yields in the 9th cropping season are average over two treatments, i.e. with and without Mg.

Treatments Giving More Than 40 t/ha

As a result of different NP interactions in Rep. I and Rep. II, the treatment that gave the highest average yield (46 t/ha) per cropping season in Rep. I was $N_2P_0K_2$, and the treatment that gave the highest average yield (45 t/ha) per cropping season in Rep. II was $N_2P_2K_2$. The average yield of control ($N_0P_0K_0$) was 36 t/ha in Rep. I and 29 t/ha in Rep. II (Fig. 4). Other treatments that gave more than 40 t of fresh roots per ha per crop are shown in Table 3.

Soil pH as Affected by Successive Cropping and Sulfate of Ammonia

The colluvial soil under this long-term experiment is classified as silty clay loam. The average organic carbon content at the time of planting the third and fifth crops was 2.1% and 1.8%, respectively. The soil in Rep. I had better drainage than that in Rep. II. Consequently the soil in Rep. II had a darker appearance than that in Rep. I. From the seventh to the ninth crop, soil pH was monitored.

It was observed that pH of the soil was decreased from 4.7 to 4.5 by fertilizing with sulfate of ammonia at the highest rate of application. Nevertheless, pH was generally increased by successive cropping with cassava including that of the soil under the highest rate of application of the fertilizer. The soil pH in the two replicates did not appear different.

Table 4. Soil N, P, and K as affected by cropping and fertilization.

	Total N (%)			Available P (ppm)			Exchangeable K (ppm)			Water-soluble K (ppm)		
Crop	N_0	N_1	N_2	P_0	P_1	P_2	K_0	K_1	K_2	K_0	K_1	K_2
Rep. I												
6th	n.a.	n.a.	n.a.	11	15	16	97	93	119	19	15	18
7th	0.14	0.14	0.14	17	17	19	65	50	78	14	12	14
8th	0.11	0.12	0.12	15	19	20	38	39	53	5	6	9
9th	0.10	0.10	0.09	5	8	9	26	27	46	3	4	6
Mean	0.12	0.12	0.12	12	15	16	57	52	74	10	9	12
Rep. II												
6th	n.a.	n.a.	n.a.	24	23	29	75	87	94	16	19	17
7th	0.14	0.14	0.13	19	22	25	48	48	47	10	9	10
8th	0.12	0.14	0.13	20	24	30	29	39	42	7	7	8
9th	0.11	0.12	0.11	14	12	19	26	24	40	4	5	6
Mean	0.12	0.13	0.12	19	20	26	45	50	56	9	10	10

NOTE: n.a. = not analyzed.

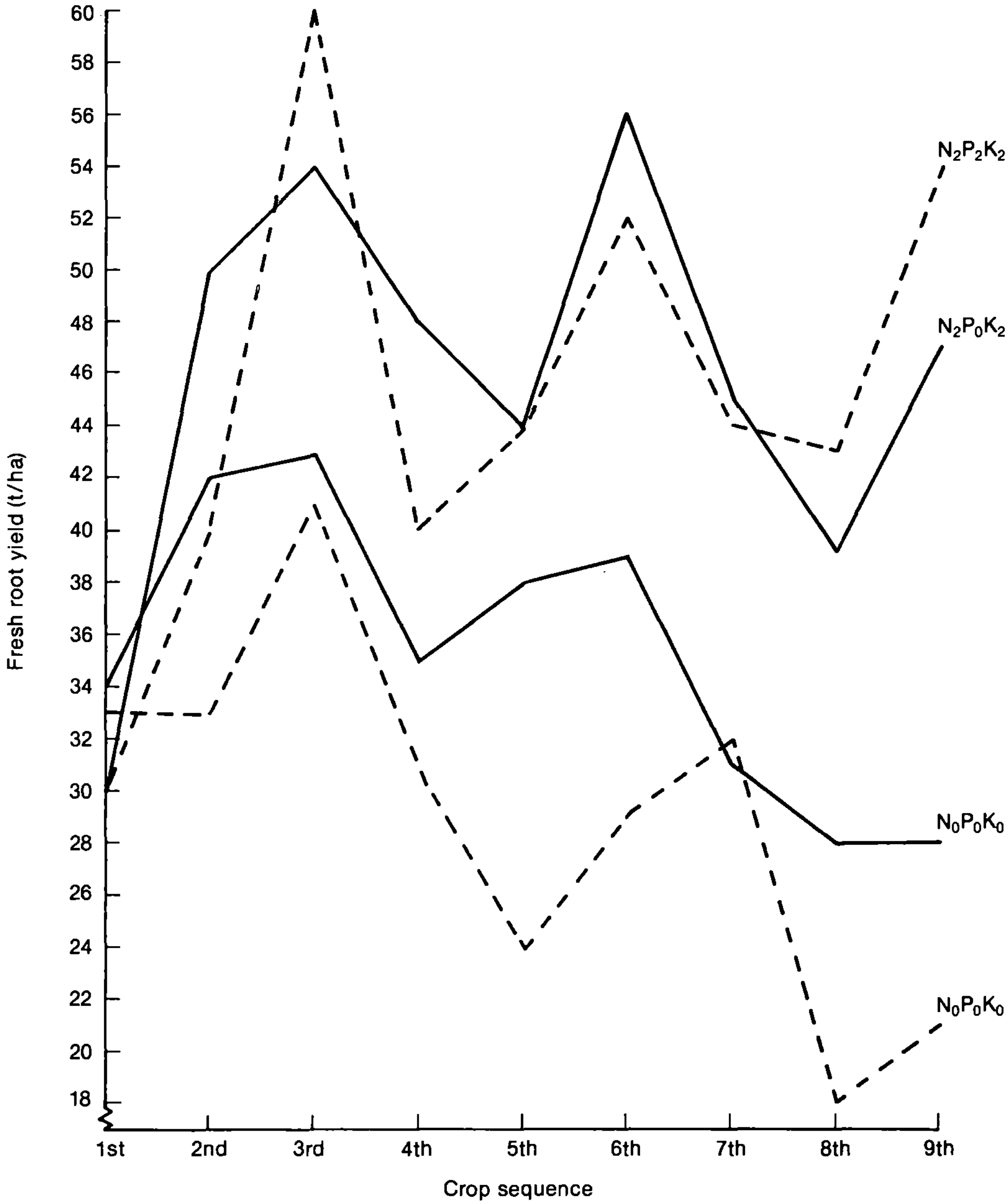

Fig. 4. Root yields of successive crops comparing unfertilized treatments in Reps. I and II with the highest yielding treatments in the respective replicates (—— Rep. I; --- Rep. II).

Table 5. Leaf and stem content of N, P, and K (%) as affected by cropping and fertilization. (Figures for leaves are means for the third to ninth crops, for the stems the figures are means for the seventh to ninth crops.)

	N_0	N_1	N_2	P_0	P_1	P_2	K_0	K_1	K_2
Leaves									
Rep. I	5.2	5.2	5.6	0.40	0.40	0.40	1.8	2.1	2.2
Rep. II	5.3	5.2	5.3	0.39	0.38	0.40	1.8	2.3	2.3
Stems									
Rep. I	0.51	0.50	0.56	0.21	0.25	0.27	0.9	1.2	1.8
Rep. II	0.51	0.55	0.57	0.21	0.24	0.24	1.0	1.2	1.7

Soil N, P, and K as Affected by Cropping and Fertilization

From the sixth to the ninth crop, the soil was monitored for levels of total N, available P, exchangeable and water-soluble K. These are shown in Table 4, where total N, available P, and available K are given for three levels of applied N, P, and K, respectively. The data are an average for nine readings.

Total soil N was reduced by cropping with cassava under all levels of N application, and was apparently not affected by N application. The mean values of soil N in Rep. I and Rep. II were nearly all the same.

Generally there was more available P in Rep. II than in Rep. I. Soil P was increased by P fertilizer applied to crops, but it declined substantially under all levels of P fertilization at the time of planting the ninth crop.

Losses in exchangeable and water-soluble K in the soil under each level of K fertilization were so great that the soil was in danger of being depeleted of available K, especially water-soluble K. Although available K in the soil was apparently increased with higher rates of K fertilization as observed at the times of planting the eighth and ninth crops, even the highest rate of K application (312 kg K_2O/ha) could not raise soil K to former levels. It is noted that the soil in Rep. I contained more exchangeable K than the soil in Rep. II.

Leaf N, P, and K as Affected by Cropping and Fertilization

The content of N, P, and K from the third to ninth crop was monitored in the leaves. It was observed that K content in the leaves was increased by the addition of K fertilizer (Table 5).

Similarly, the content of leaf N was increased by N fertilization as seen in most of the crops of Rep. I, but this increase was not apparent in Rep. II except in the third and eighth crops. The effect of P fertilizer on the content of leaf P was not detectable. However, the fluctuations of leaf nutrient levels with cropping seasons did not reflect the declining fertility of the soil as expected under conditions of no fertilizer applications.

Contents of N, P, and K in the Stem as Affected by Cropping and Fertilization

Analyses were performed to determine the N, P, and K content in the stems of the seventh, eighth, and ninth crops. It was observed that the content of K in the stem became less and less with cropping, reflecting the decline in soil fertility with respect to content of K in the soil. A similar trend of decrease in stem uptake of N was observed in the seventh and eighth crops that were analyzed, but a difference between the two crops in the uptake of P was not apparent.

Nutrient Removal by Cassava

The first crop of Black Twig, which yielded 28 t of roots per hectare, is estimated to have removed in total about 88 kg N, 32 kg P, 181 kg K, 39 kg Ca, and 16 kg Mg (Table 6). These are equivalent to 88 kg N, 73 kg P_2O_5, 218 kg K_2O, 55 kg CaO, and 27 kg MgO.

Based on the above figures, a crop with a yield of 40 t of roots per hectare is estimated to remove 126 kg N, 46 kg P, 259 kg K, 56 kg Ca, and 23 kg Mg. These are equivalent to 126 kg N, 105 kg P_2O_5, 312 kg K_2O, 78 kg CaO, and 38 kg MgO.

Therefore, the quantities of N, P, and K removed by successive crops with an average

Table 6. Estimated quantities of N, P, K, Ca, and Mg removed by the various plants of the 1st crop at harvest (kg/ha).

	Leaves	Leaf stalks	Stems	Roots
N	20.4	1.5	21.9	44.5
P	1.4	0.5	10.0	19.8
K	8.4	3.0	50.3	119.5
Ca	4.8	2.8	21.3	10.0
Mg	1.3	0.4	7.3	7.2

fresh-root yield of 40 t/ha would have exceeded the highest annual application rates of N (112 kg/ha), P_2O_5 (68 kg/ha), and K_2O (156 kg/ha). Later, in the eighth and ninth crops, raising the highest application rate of K to 312 kg K_2O/ha just matched the estimated quantity of K removed by the crop with 40 t of fresh root yield per hectare.

Because nearly one-third of the total quantity of nutrients are found in the stems, possibilities for reducing nutrient consumption exist in the selection for suitable short varieties, and in planting of longer stakes to reduce the number of discarded stems at harvest, especially for tall, unbranched cultivars. Increases in yield as a result of using 60-cm stakes for vertical planting have been reported (Normanha and Pereira 1950; Loria 1962; Chan 1975). To redeem soil fertility, a fallow under leguminous cover should be included for cassava production.

Notes on Fertilization Practices in Plantations and Smallholder Farms

One of the causes that led to the closure of two large cassava plantations in Malaysia was the decline in yields with successive monocropping from 30 to 18 t/ha on clay loam soil, and from 25 to 8 t/ha on sandy soil, where the application rates per crop per hectare in both plantations were 47 kg N, 24 kg P_2O_5, 87 kg K_2O, and 12 kg MgO. Based on consumption figures for Black Twig, none of the applied nutrients were comparable in quantity to that consumed by cassava yielding 25–30 t/ha of roots. As the soils became poorer with repeated cropping, the fertilizer could not supply enough nutrients to maintain yields at initial levels.

Nevertheless, the majority of cassava roots are produced by smallholders. In a study of 58 smallholders who have been growing cassava for 10–20 years or more in the major cassava-producing state of Perak, most of them practice rotation with other crops such as groundnuts, vegetables, and sweet potatoes (Chung 1976). In this majority group, some apply chemical fertilizers to cassava, some use a combination of organic manure like pig's dung and wood ash, and some do not apply any fertilizer. In the case of those who use chemical fertilizers, it is estimated that they apply 127–184 kg N, 48–80 kg P_2O_5, and 77–124 kg K_2O/ha. For cassava yielding 30 t/ha of roots, said to be obtained by smallholders that use fertilizer, it is noted that they apply N and P in quantities comparable with those consumed by cassava, whereas the applied K is less. To maintain the yield at this level, the K deficit must be balanced, possibly by an excess of K applied to another crop in the rotation or the release of K from its residue.

Experiment (b)

Establishment of the plants was 100% in both experiments. Owing to basal application of the NPK mixture, the plants in Expt. (i) were generally taller than those in Expt. (ii). The eight types of stakes are differentiated according to their manurial history. Table 7 shows the residual manurial effects in the cuttings on fresh-root yields of plants 6 months after planting.

The residual effect of phosphorus in the stakes was important when no NPK mixture was applied to the current crop. It became insignificant when the NPK mixture was applied. More important was the residual effect of potassium. The stakes with a previous history of potassium fertilization produced more yield of roots than those without it, regardless of whether the NPK mixture was applied to the current crop or not. Nitrogen fertilization left no important residual effect in the stakes. These findings are comparable with those of Keating et al. 1979, who showed that fresh-root yield of cassava 8 months after planting was increased significantly by using stakes from plants that had received preharvest fertilizer treatment.

The N, P, and K contents of the various types of stakes were determined by chemical analyses of stake samples from the eighth crop in Rep. I. The biggest difference in nutrient content of the cuttings due to previous fertilization was that between those with a history of K fertilization and those without it. The average content of K in the latter type of stakes was abnormally low, only 0.75%.

Table 7. Effect of residual manure on fresh-root yields (t/ha) of 6-month-old plants with (Exp. ii) and without (Exp. i) basal fertilizer application.

	Without NPK		With NPK	
Manurial history	Effect means	Root yield	Effect means	Root yield
Control		12		21
N	−0.34	14	−3.54	19
P	6.31*	15	0.83	21
NP	−0.51	17	0.07	21
K	6.51*	17	4.83*	25
NK	−4.58	15	−0.71	23
PK	−0.53	21	−2.06	23
NPK	−0.14	18	−0.36	22
L.S.D. (p=0.05)	5.73		4.53	

*Significant difference at 5% level.

The residual effects of phosphorus and potassium in the stakes have important implications with regard to maintenance of high root yields. In Expt. (a) on successive cropping with cassava, the decline in root yields in all those plots that did not receive fertilizer, particularly potassium, would have been more pronounced if plants from the same plots were used as planting materials. In cassava farms, replanting with stakes taken from plants having the same manurial treatment is a general practice. Where the standard fertilizer practice does not provide sufficient nutrients, particularly potassium, planting materials within the farm will become poorer. This will further aggravate any subsequent decline in yield due to an inadequate external supply of nutrients.

Conclusions

Yield and the number of consecutive crops having similar yields are expected to vary with soils, climate, varieties, and cultural practices. Therefore, the experimental data should not be used for determining the economics of cassava production. From these studies the following conclusions were made.

(1) If seasonal differences in other factors, such as rainfall, organic matter content of the soil, and fallow period, were not large enough to affect root yield, then a constant yield for successive crops could be maintained by continually increasing the application rates of those nutrients in short supply, which eventually would be high enough to equal or exceed those removed by the crop at harvest.

(2) When a decline in the yield of cassava can be eliminated by applying more of a particular nutrient, this means its availability in the soil has decreased and a greater supply from an external source is required. Thus, if the rate of fertilizer application were increased just enough to maintain the same yield as before, soil fertility would continue to decrease until an equilibrium was reached.

(3) Successive cropping with cassava will result in an increasing demand for applied K. But the effects of N and P on root yield may be complicated by the occurrence of different NP interactions. An increase or decrease in yield may result from either applying both N and P or applying one nutrient in the absence of the other. It is necessary to investigate the causes of these interactions and to determine whether NP interactions are important in different cassava growing areas.

(4) Regular applications of only N, P, and K to successive cassava crops will eventually bring about foliar symptoms of Mg deficiency. When this occurs, application of Mg to the following crop will correct the deficiency and increase yield.

(5) If stakes are equally fertilized with K, those originally deficient in K may produce lower root yields than those that were not deficient.

(6) The pH of the soil may be decreased by increasing the rate of application of ammonium sulfate as nitrogen fertilizer, but it will be increased by successive cropping with cassava even when ammonium sulfate is regularly applied to the soil.

(7) The nutrient status of the leaves 3 months after planting fluctuates with season of planting; as such it is unable to give indications of decreases in the nutrient uptake of the plant or the nutrient availability in the soil. The nutrient status of the stake at harvest appears useful in providing such diagnostic indications.

(8) As judged by present cultural practices for cassava, whether grown as monocrop or in rotation with other crops, soils that have been under cultivation with cassava for many years are expected to have become poorer, regardless of whether cassava crops have not been fertilized or have been fertilized just enough to maintain similar yields.

(9) Like the soil in which they grow, cassava planting materials are also a reservoir of nutrients that may become deficient for plant growth. In the case of little or no fertilization, low yield will be followed by lower yield because the farmer uses the same land and the same source of planting materials, both of which become poorer in nutrient content with each successive season of cropping.

(10) To check increasing fertilizer requirements caused by a decrease in natural fertility of the soil, high priority should be given to the breeding for more efficient, less nutrient-demanding varieties and the development of cultural practices that are both applicable and effective in maintaining yield and soil fertility at desirable levels.

(11) Cassava production seems more viable under smallholder than plantation conditions, not because the smallholder always grows a better crop, but because he does not depend on growing cassava alone for a living. Moreover, for the smallholder who manages to maintain consistent yields, he does not have to depend entirely on the use of chemical fertilizers.

The writer expresses his appreciation to the Department of Agriculture and the Malaysian Agricultural Research and Development Institute for permission to carry out the long-term fertility trial with cassava. Thanks are due to Mr Mohamad Isa bin Hassan for his commendable assistance in the field. Appreciation is extended to Mr Abas bin Abdul Ghani and Dr Heng Cheng Kok for laboratory services and to Dr Lee Chong Soon for some statistical advice and services.

The writer also expresses his gratitude to Dato' Mohamad Tamin bin Yeop (Director General of MARDI) for permission to present the paper, and to the International Development Research Centre for financial assistance to participate at the Workshop. The long-term fertility study was part of the MARDI–IDRC Cassava Research Project from January 1975 to December 1979.

Cassava Production in Low Fertility Soils

Jaime de Cerqueira Gomes[1] and Reinhardt H. Howeler[2]

Although cassava has a reputation for producing acceptable yields in poor soils it produces higher yields with adequate application of fertilizers, especially phosphorus in the Brazilian situation. Research carried out in Brazil has shown that although nitrogen uptake by cassava is high, it does not always result in yield increases. In some cases productivity has been reduced. However, when applied as organic matter very good responses have been obtained.

Phosphorus is low in most Brazilian soils and when it has been applied it has been responsible for large root-yield increases. This nutrient is usually applied in its most soluble forms as simple superphosphate and triple superphosphate. The use of phosphate rock in acid soils offers potential for increasing cassava productivity at a lower cost. Potassium applications induce small increments in yield, but are more effective than nitrogen. Generally yield increases due to potassium and nitrogen occur more frequently in the presence of phosphorus. Limestone applications to correct soil pH or to provide a source of calcium and magnesium generally have not produced significant yield increases. Sulfur and zinc applications in the Cerrados have induced positive effects on production, whereas zinc and manganese have shown positive results in the northern states. Starch content has been consistently increased by fertilizer applications, especially potassium.

Cassava is grown throughout Brazil because the crop is well adapted to adverse ecological conditions. Although cassava is a supplier of raw material for several industrial products (some of them exports), in northeastern Brazil it is mainly considered a subsistence crop. However, cassava has outstanding potential as a raw material for the production of alcohol.

One of the aspects that accounts for low yields in cassava is the use of infertile soils, which are especially low in phosphorus, without the use of fertilizers. This paper presents research results of studies carried out in low fertility soils, mainly in the Llanos Orientales of Colombia and in some Brazilian states.

Nutrient Demands

For plants to reach full development and maximum production, they need to absorb nutrients. The quantities absorbed vary according to the species and cultivar.

[1]Agricultural Engineer, EMBRAPA/CNPMF, Cruz das Almas, Bahía, Brazil.

[2]Soil Scientist, Cassava Program, CIAT, Cali, Colombia.

Howeler (1976), reviewing the literature, showed that cassava absorbed potassium and nitrogen in large quantities. Results obtained by CNPMF on dry-matter production in three cultivars (BGM-2, BGM-116, and BGM-072) showed that when only the roots were considered, cassava absorbed nutrients in the following order: K, N, Mg, Ca, P, S (EMBRAPA/CNPMF 1979).

Preliminary studies on the responses of cassava and other crops (legumes and grasses) to the application of 40–80–40 kg/ha of N, P_2O_5, and K_2O showed that cassava had a relatively low response. In general, the critical level of soil nutrients for cassava appears to be lower than that of legumes and grasses.

Fertilizer Effect

Pot Experiments With Soil or Nutrient Solutions

In sand culture with nutrient solutions at five concentrations of N, P, and K, Howeler (1976) found that the optimum solution concentration of N for cassava was above 80 ppm, whereas those for P and K were 5 and 40 ppm, respectively.

Malovolta et al. (1953, 1954) showed that in sand culture cassava yields were most affected by lack of P followed by N and K. In the absence of P, starch content was sharply reduced from 32 to 25%. Doubling the N level in the presence of P and K resulted in the best yield although the starch content was reduced to 24%, and crude protein increased from 2.01 to 5.14%.

In pot trials with soil of the Llanos Orientales of Colombia, Howeler (1976) obtained outstanding responses to phosphorus both in terms of root yields and top yields at 6 months. Maximum production was obtained with 100 and 200 kg/ha of P_2O_5, respectively, for triple superphosphate and basic slag. In another trial with the same fertilizers, responses were obtained to 50 and 100 kg/ha of P_2O_5. The residual effect of 200 kg/ha of P_2O_5 corresponded approximately to the recent application of 25 kg of P_2O_5. With respect to K, the highest root yields were obtained with 200 kg/ha of K_2O.

Krochmal and Samuels (1970) determined the effect of different levels of N, P, and K in a nutrient solution and concluded that high levels of N increased top growth but reduced root growth.

A high P level not only increased plant height but also produced highest root yields. High levels of K reduced top growth and did not increase root yields.

Field Experiments in Colombia — Fertilization with NPK, Lime, and Zn

Howeler (1976) reported cassava responses to different levels, sources, and times of application of N in Carimagua. Yields increased up to 200 kg/ha, and ordinary urea was more effective than sulfur coated urea (SCU). Application of 25% of N at 50 days, 25% at 85 days, and 50% at 120 days after planting, resulted in better yields than a total application at 60 days.

Another trial on N levels (0, 50, 75, 100, and 150 kg/ha), applied as urea at the time of planting or fractionated at 30, 120, and 150 days after planting, showed a negative response to the higher doses when applied all at planting. This effect was probably due to the dry season following the application. The best fractionation was 50% of N at 30 days, 25% at 120 days, and 25% at 150 days after planting. Nitrogen should be applied partially at planting, and after 30 days during the rainy season (CIAT 1976). In medium fertility soils of Caldas, Colombia, Rodriguez (1975) studied the effect of different levels of N, P_2O_5, and K_2O, as well as the fractionation of 100 kg of N. Maximum yields were obtained with 145 kg of N, 194 kg of P_2O_5, and 46 kg of K_2O/ha. One single nitrogen application at planting resulted in better yields compared to application in two doses. In different soils of Antioquia, Colombia, Rodriguez (1975) found that the reponse depended on the soil fertility. In low fertility soil, maximum yields were obtained with 82–125 kg/ha N, with 163–300 kg/ha P_2O_5, and with 100–127 kg/ha K_2O. Liming was beneficial in soils with less than 4.6 meq Ca/100 g soil. Fractionation of N and the application of micronutrients (Zn, Cu, B, and Mo) did not have much affect on production.

A trial on the interaction of P and K using 15 levels of each element (CIAT 1976), showed that the highest yields were obtained with 140 kg/ha of P_2O_5 and of K_2O. Responses to different K levels were small but responses to phosphorus were much larger.

A study of N $\times$ K interaction, with levels of 0, 100, and 200 kg/ha N and 0, 150, and 300 kg/ha K_2O (CIAT 1975), showed that cassava responded to N only in the presence of potassium and that this response was positive only up to 100 kg/ha N, whereas the application of 200 kg/ha N resulted in a negative response. There were positive responses to the application of 150 kg/ha of K_2O both in the absence and presence of N.

Comparing different K sources, it was observed that plants treated with KCl showed a yellowing of lower leaves, indicative of S deficiency, at 3 months. With the use of K_2SO_4 or KCl mixed with S, plants showed normal development. Cassava yields were better with K_2SO_4 or KCl + S than with KCl alone (CIAT 1975).

In a comparison of various P sources, average root yields of 7.5, 13.9, 17.1, and 19.9 t/ha were obtained with the application of 0, 50, 100, and 400 kg P_2O_5/ha. The higher yields were obtained with triple superphosphate and basic slag; the responses to rock phosphates depended on their degree of solubility. There was no significant difference between the tested sources except for the least soluble rock phosphate. The solubility of rock phosphate improved considerably when partially acidified or when mixed with elemental sulfur (CIAT 1976).

Cassava yields increased with the application of 1/2 to 2 t/ha of lime to these very acid soils. An application of 6 t/ha resulted in yield decreases and many cultivars showed chlorosis and malformation of terminal buds. Positive responses to high applications of lime were obtained only in the presence of applied Zn. Other trials showed that yields were increased 10 t/ha with Mg application (50 kg/ha) in the form

Table 1. Response of cassava (root yield in t/ha) to different levels of application of N, P, and K (kg/ha N, P_2O_5, and K_2O) in various locations in Brazil.

	São Paulo		Rio de Janeiro				Pernambuco	Paraiba	Sergipe			Bahía						
	Sorocaba	Sorocaba, Araras, & Tiete	São João da Barra	São Pedro da Aldeia	Paraiba	Rio Grande do Norte	Goiana	Rio Tinto	Lagarto	Estancia	N.S. Dores	C. Almeida	Irará	Itiruçu	Jaguaquara	Sapeaçu	C. Almeida	Irará
N_0	16.9	21.7	24.3	23.2	12.0	19.9	7.9	6.4	11.3	26.5	16.4	19.2	14.2	18.9	26.6	21.0	24.1	23.8
N_1	19.7	22.6	24.6	22.2	14.1	20.6	10.5	6.6	12.0	28.6	17.7	19.0	14.7	17.2	27.5	23.2	27.8	24.5
N_2	21.0	21.7	25.4	23.0	15.9	21.1	11.1	10.1	13.3	28.5	16.2	21.6	13.6	17.3	26.1	22.3	33.0	26.4
P_0	13.9	13.6	17.3	23.1	4.9	8.7	4.2	1.0	3.0	14.3	4.0	15.8	5.0	14.1	24.9	17.9	27.6	15.9
P_1	16.6	18.5	27.4	24.3	17.8	25.5	9.1	9.1	17.7	32.6	22.0	20.3	18.1	19.3	27.3	25.4	27.8	29.1
P_2	21.0	21.7	29.5	21.1	19.3	27.3	11.1	10.1	16.0	36.6	16.9	23.9	19.3	20.1	29.0	23.2	29.4	29.7
K_0	19.1	22.5	24.0	21.0	13.7	19.5	9.8	10.0	14.2	27.7	14.6	17.8	10.4	19.3	25.4	22.1	24.1	23.6
K_1	21.2	21.4	25.1	23.9	14.0	20.7	11.1	10.2	12.6	28.2	18.3	21.3	15.1	16.7	23.6	20.9	29.5	24.4
K_2	21.0	21.7	25.1	23.6	14.3	21.4	11.1	10.1	9.6	27.7	17.3	20.8	17.0	17.4	27.2	23.5	31.4	26.7

State	Location	No. of experiments	Fertilizer applied N_0, N_1, N_2	— P_0, P_1, P_2	— K_0, K_1, K_2	Reference
São Paulo	Sorocaba	2	0,40,80	0,60,120	0,30,60	Normanha and Pereira 1950
	Sorocaba, Araras, and Tiete	3	0,40,80	0,60,120	0,30,60	
Rio de Janeiro	São João da Barra	3	0,15,30	0,40,80	0,20,40	Nunes et al. 1974
	São Pedro da Aldeia	1	0,15,30	0,40,80	0,20,40	Nunes et al. 1974
Paraiba	Santa Rita	1	0,80,160	0,60,120	0,60,120	Silva 1970
	Rio Tinto	1	0,40,80	0,36,72	0,60,120	Silva et al. 1969
Pernambuco	Goiana	1	0,40,80	0,80,160	0,60,120	Silva et al. 1969
Rio Grande do Norte	Macaiba, Varzea, and São Jose Mipibu	6	0,20,40	0,95,145	0,47,94	Rio Grande do Norte/ Secretaria da Agr. 1971–75
Sergipe	N.S. Dores, Lagarto, and Estancia	3	0,60,120	0,60,120	0,60,120	Sobral et al. 1976
Bahía	C. Almeida, Irará, Itiruçu	3	0,60,120	0,60,120	0,60,120	Gomes et al. 1973
	C. Almeida, Irará, Jaguaquara, and Sapeaçu	8	0,60,120	0,60,120	0,60,120	Gomes et al. 1979b

of $MgSO_4 \cdot 7H_2O$. Higher levels of Mg caused a yield reduction and possibly led to induced Ca deficiency (CIAT 1975).

Comparing the use of farmyard manure with that of chemical fertilizer it was found that the application of 20–30 t/ha of manure doubled the yields. Adding 80 kg/ha P_2O_5 and 150 kg/ha K_2O to the manure increased yields significantly. Application of chemical fertilizers (10–20–20) was better than manure applied alone, but not significantly different from manure fortified with superphosphate or KCl.

Zinc deficiencies were observed in acid as well as alkaline soils. Significant yield increases were obtained in acid soils with 5 kg/ha Zn applied to the soil. There was not a significant difference between band applied $ZnSO_4 \cdot 7H_2O$ and broadcast application. Foliar applications and stake treatments were less effective than soil applications. Critical levels in the upper leaves at 3 months varied with the two tested cultivars from 37 ppm for M Mex 59 to 51 ppm for M Mex 23. Better yields of cultivar Llanera in alkaline soils were obtained when stakes were immersed in a suspension of ZnO at 4% or in a solution of 4% $ZnSO_4 \cdot 7H_2O$ for 15 min. High yields were related to a high zinc content (more than 45 ppm) in upper leaves. Thus, soil application is recommended for acid soils and stake treatments are suggested for alkaline soils (CIAT 1977).

Varietal Tolerance to Soil Acidity and Low Levels of P and K

Cassava was found to be rather tolerant to high levels of aluminium in nutrient solutions. Growth in a solution containing 3 ppm of Al was better than without Al. Under field conditions in Carimagua, using 0, 0.5, 2.0, or 6.0 t/ha lime it was found that pH increased from 4.3 to 5.3 and that exchangeable aluminium decreased from 2.0 to 0.3 meq/100 g. A reduction of growth and deficiencies of Ca and Mg were observed in the absence of lime. Average yields from 42 cultivars indicated that cassava was more tolerant to acid soils than corn, rice, sorghum, and beans and had about the same tolerance as cowpea. On the average, cassava reached a maximum yield of 40% in the absence of lime. Cultivar M Col 1604 produced without lime 80% of the yield obtained with 2 t/ha lime. Llanera, used as the control cultivar, proved to be less tolerant, producing 50% of its maximum yields. It was concluded that cassava is more tolerant of acid soils than many other crops (CIAT 1977).

Tolerance to low levels of available P were determined in 100 cultivars grown in plots with 0 and 150 kg/ha of P_2O_5 applied at planting. Without P, yields were only 29% of that obtained with P. Cultivar M Col 1604 proved to be most tolerant, but Llanera showed a low level of tolerance. In another trial with 160 cultivars, M Mex 59 was found to have a high level of tolerance to low P. The same cultivars used to determine P tolerance were also used to study K tolerance by application of 0 and 200 kg/ha K_2O. The absence of K resulted in a slight reduction in plant growth and K content in the upper leaves. On the average, the lack of K reduced yields to 70% of maximum (CIAT 1977).

Field Experiments in Brazil — Fertilization with N, P, K, Lime, S, and Micronutrients

Under field conditions, best responses were generally obtained with the application of phosphate fertilizers. In São Paulo, Normanha and Pereira (1950) showed that phosphorus application results in the greatest yield increases. Nitrogen and potassium when applied separately did not show any influence, but when combined with P they increased yields. Highest yields were obtained with 80 kg/ha N, 120 kg P_2O_5, and 60 kg K_2O (Table 1).

Results of 140 experiments carried out in the State of São Paulo by the Agronomical Institute of Campinas showed that the greatest increases in fertilization were due to phosphorus (Silva et al. 1979). Recent experiments in Araras, São Paulo, comparing phosphorus sources such as simple superphosphate, triple superphosphate, bonemeal, and rock phosphates, from Araxá and Olinda indicated no significant responses to P applications. Average root yields of the seven experiments varied between 22.3 and 25.5 t/ha. The lack of responses was due to the use of soils that had been fertilized for other crops prior to cassava (Silva et al. 1979).

Lime and micronutrient effects on cassava production were also studied in São Paulo. Results showed that neither liming nor micronutrient applications affected cassava yields. Boron application slightly decreased yields (Table 2). Nunes et al. (1974) conducted seven experiments at two locations in the State of Rio de Janeiro on levels of N, P, and K. Phosphorus was the most important element for increasing yield in the five experiments in São João da Barra, but the other two experiments in São Pedro da Aldeia did not show significant yield responses although chemical analysis showed low levels of nutrients in the soil (Table 3).

Table 2. Average root yields (t/ha) of seven experiments, Araras, São Paulo.

Treatments	With lime	Without lime	Average
NPK + B (10 kg/ha borax)	24.6	25.3	25.0
NPK + Cu (20 kg/ha copper sulfate)	29.3	27.8	28.6
NPK + Fe (20 kg/ha iron sulfate)	27.7	27.2	27.5
NPK + Mg (20 kg/ha magnesium sulfate)	25.9	26.7	26.3
NPK + Mn (20 kg/ha manganese sulfate)	27.9	28.1	28.0
NPK + Mo (0.5 kg/ha ammonium molibdate)	24.6	28.3	26.5
NPK + Zn (20 kg/ha zinc sulfate)	30.6	28.2	29.4
NPK + micronutrients	29.0	31.0	30.0
NPK + micronutrients + magnesium	28.7	28.4	28.6
NPK (40, 80, and 50 kg/ha of N, P_2O_5, and K_2O)	26.3	28.4	27.4
Average	27.5	27.9	27.7

Chemical characteristics of the soil: pH 4.20–5.15; C 0.68–1.56%; Ca^{++} + Mg^{++} 0.30–3.3; Al^{+++} 0.30–1.80; K^{+} 0.04–0.13; and PO_4^{-3} 0.02–0.04 meq/100 ml.

Table 3. Characteristics of soils in which cassava experiments have been conducted in Brazil.

Location	pH	Al (meq/ 100 g)	Ca+Mg (meq/ 100 g)	K (ppm)	P (ppm)	OM (%)	Soil classification
São João da Barra, Rio de Janeiro	5.8	0.6	2.1	57	0.4	—	Oxisol
São Pedro da Aldeia, Rio de Janeiro	6.1	0.0	2.5	44	0.0	—	Oxisol
Felixlandia, Minas Gerais	4.7	0.7	0.5	20	2.0	1.8	Dark red oxisol
Lagarto, Sergipe	6.3	0.0	3.9	44	2.0	—	Red-yellow podzol
Estancia, Sergipe	4.9	0.9	0.7	20	3.0	—	Red-yellow podzol
N. Sra das Dores, Sergipe	5.7	0.4	1.7	36	2.0	—	Red-yellow oxisol
C. Almeida, Bahía	5.1	0.3	1.0	36	3.0	—	Oxisol
Irará, Bahía	5.4	0.1	1.6	19	1.6	—	Oxisol
Jaguaquara, Bahía	5.7	0.1	3.9	94	7.3	—	Oxisol
Sapeaçu, Bahía	4.9	0.5	1.5	35	2.5	—	Oxisol
Cruz das Almas (CNPMF), Bahía	4.9	0.1	1.7	37	3.0	1.0	Red-yellow oxisol

Tanaka et al. (1979) conducted experiments on liming and fertilization of P and K in Felixlandia, Minas Gerais. The soil of this Campo Cerrado region is a dystrophic dark red oxisol of sandy-clay loam texture. This was the first time it had been planted. Chemical characteristics are shown in Table 3. Treatments included 0, 3, and 6 t/ha lime, and 0, 60, and 120 kg/ha of P_2O_5 and of K_2O. Root yields indicated no significant effect of individual factors or interactions. Significant increases in foliage yield were obtained due to application of phosphorus (Table 4). In the same region Correa et al. (1979) studied the effect of potassium levels and time of application (Table 5). Although the K levels were low in the soil, there was only a significant response to 60 kg K_2O/ha, with no differences in times of application.

Studies carried out in northeastern Brazil showed positive responses to application of organic manures and phosphate fertilizers and responses to liming in some cases. Recent experiments in Manaus using two P sources, with or without lime, showed small positive responses to liming and significant responses to application of P (Fig. 1). Triple superphosphate was superior at low rates of applied P, but rock phosphate was equally effective at high rates. In oxisols of the Tabuleiros Costeiros of the State of Paraiba, Silva (1970) obtained greatest responses to P followed by N. Responses to K were not significant in this study (Table 1).

Studies carried out in 1971 and 1975 in different locations of Rio Grande do Norte in acid, low-P soils (mainly dystrophic red-yellow oxisols), showed good responses to organic and

Table 4. Cassava root and top yield responses (t/ha) to the application of three levels of lime (t/ha), P (kg/ha P_2O_5), and K (kg/ha K_2O) in Felixlandia, M.G. (Tanaka et al. 1979).

		Root yield				Top yield			
Lime	K	P_0	P_{60}	P_{120}	$\bar{X}$	P_0	P_{60}	P_{120}	$\bar{X}$
0	0	29.5	23.7	20.7	24.6	27.2	41.4	33.1	33.9
3	0	23.4	26.1	24.6	24.7	20.9	38.1	39.6	32.9
6	0	25.4	28.5	23.1	25.7	24.4	28.4	32.2	28.3
0	60	19.5	25.6	26.0	23.7	29.9	43.5	43.0	38.8
3	60	25.4	23.1	26.2	24.9	38.4	39.3	35.2	37.6
6	60	25.3	24.7	31.0	27.0	38.4	38.6	42.3	39.8
0	120	22.6	22.6	21.0	22.1	26.4	34.5	49.3	36.7
3	120	20.7	23.8	24.8	23.1	29.4	32.9	39.8	34.0
6	120	17.8	22.8	19.2	19.9	31.3	31.5	30.7	31.2
$\bar{X}$		23.3	24.5	24.1		29.6	36.5	38.3	
Lime	P	K_0	K_{60}	K_{120}	$\bar{X}$	K_0	K_{60}	K_{120}	$\bar{X}$
0	$\bar{X}$ (0,60,120)	24.6	23.7	22.1	23.5	33.9	38.8	36.7	36.5
3	$\bar{X}$ (0,60,120)	24.7	24.9	23.1	24.2	32.9	37.6	34.0	34.8
6	$\bar{X}$ (0,60,120)	25.7	27.0	19.9	24.2	28.3	39.8	31.2	33.1
	$\bar{X}$	25.0	25.2	21.7		31.7	38.7	34.0	

Table 5. The effect of levels and times of application of K (kg K_2O/ha) on cassava root yield (t/ha) in Felixlandia, M.G. (Correa et al. 1979).

Time of application (days)		K application					
0	60	0	60	120	240	360	$\bar{X}$
100%	0%	20.0	21.3	20.6	27.5	28.3	24.4
50%	50%	—	20.5	24.1	18.9	24.4	22.0
33%	67%	—	29.3	22.1	22.1	24.0	24.4
	$\bar{X}$	20.0	23.7	22.3	22.8	25.5	

phosphate fertilization. In these trials root yields increased from 9 to 30 t/ha with application of 6 t/ha manure (Fig. 2). High rates of manure were detrimental probably due to excessive top growth. Application of different levels of N, P, K showed that P was the most important element for increasing yield (Table 1). Application of other nutrients did not have a significant effect. The recommended phosphorus dose is between 80 and 100 kg/ha P_2O_5. An application of 30 kg/ha N and 25 kg K_2O is recommended to maintain soil fertility.

Silva et al. (1969) carried out experiments in Tabuleiros Costeiros in the states of Pernambuco, Rio Grande do Norte, Alagoas, and Paraiba to test the effect of N, P, K, and manganese using manganese sulfate, in doses of 0, 30 and 60 kg/ha of MnO. Results showed variations between the different localities. Phosphorus was the element producing greatest yield increases, followed by nitrogen (Table 1). Manganese application was effective only in Goiana, Pernambuco, where deficiency symptoms had been observed. Fernandes (1972) observed chlorotic plants in cassava fields located in the northeastern part of the Tabuleiros Costeiros as well as in the coastal strip, which has dunes of white sand. Analysis of soils near roots showed that symptoms were associated with lime residues or shells and that pH of the soil was alkaline. Leaf infiltration tests, using hydroxides and chelates of iron, zinc, and manganese, showed recuperation from chlorosis in treatments with manganese.

Research carried out through the former Instituto de Pesquisas e Experimentação Agropecuária do Leste, which is now known as the National Research Center for Cassava and Fruit Crops (CNPMF), showed that cassava responded mainly to phosphate fertilization. Siqueira (1973) obtained responses with P application in Tabuleiros soil in the state of Sergipe. Results

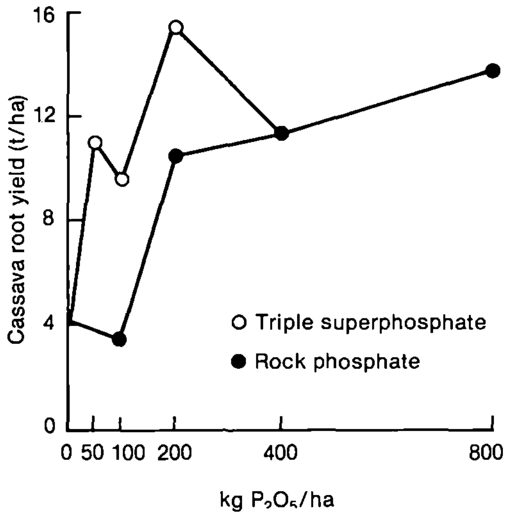

Fig. 1. The response of cassava to different levels of P applied as triple superphosphate or rock phosphate in Manaus, A.M. (EMBRAPA/UEPAE 1979).

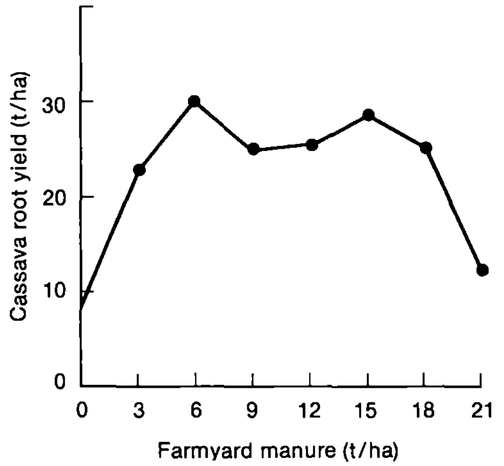

Fig. 2. The average response of cassava to different levels of farmyard manure applied in four experiments in Rio Grande do Norte (Silva 1970).

showed that application of this element alone was able to increase yields. Application of organic manure increased yields significantly but was less effective than chemical fertilizers containing P (Table 6). Sobral et al. (1976) studied the effect of N, P, K, lime, and sulfur, micronutrients, and organic manure in Sergipe and found good responses to phosphorus in the three locations they studied (Table 1). There was no response to lime, and an S response in only one location.

Table 6. Response of cassava (root yield, t/ha) to fertilization with N, P, and K, as well as organic manure at two sites in Sergipe (Siqueira 1973).

Treatments[a]	N.S. das Dores[b]	Capela
Without fertilizer	7.7	14.2
P	24.2	27.3
NP	24.1	26.5
NPK	27.1	26.9
P + organic manure	24.0	25.8
Organic manure	16.3	19.8

[a]N, P_2O_5, and K_2O: 80, 90, and 60 kg/ha, respectively.
[b]Red-yellow oxisol.
Sources: ammonium sulfate, simple superphospate, potassium chloride, and oil cake (organic manure).

Gomes et al. (1973) studied N, P, and K in oxisols in Bahia (Tables 1 and 3) and concluded that: (a) nitrogen fertilization had no effect on yield; (2) phosphorus fertilization was highly beneficial increasing yields from 5 to 19 t/ha with application of 120 kg P_2O_5/ha in one experiment in Irará; and (3) potassium fertilization significantly increased yields in two of the three locations (Table 1).

The interaction P × K was significant in these two sites. Results obtained with sulfur application, micronutrient mixture (Zn, Cu, B, and Mo), liming, and organic manures did not show significant effects. The micronutrient mixture showed a positive effect in one of the sites (Irará) in which the greatest responses to phosphorus and potassium were obtained.

Gomes et al. (1979a,b,c) later confirmed these results in a series of eight experiments in Bahia in soils with characteristics similar to those shown in Table 3. In general nitrogen responses were low, showing only a significant effect in one experiment. Significant effects of P application were observed in the four experiments conducted in Irará, Sapeaçu, and Jaguaquara, Bahia. The average optimum yield was obtained with 85 kg/ha P_2O_5 with an estimated root production of 32 t/ha. Potassium application gave significant effects only in two experiments conducted in Conceição do Almeida. No significant responses were obtained with applications of lime, S, and micronutrients.

At the CNPMF headquarters in Cruz das Almas, Bahia, in a red-yellow oxisol of medium texture (Table 3), fertilization experiments are under way to study levels, times, and methods of application of N, P, and K, as well as sources and critical levels of phosphorus.

Table 7. Average root production of cassava cv. BGM-001 as affected by levels and time of application of nitrogen, CNPMF 1977/78 (first planting).

N (kg/ha)[a]	Application period[b]						Average
	E_1	E_2	E_3	E_4	E_5	E_6	
40	38.4	32.4	35.7	34.8	37.7	35.1	35.7
80	33.8	34.4	37.6	37.6	36.8	33.9	35.7
120	29.9	38.7	31.9	40.7	38.5	39.1	36.5
Average	34.0	35.1	35.1	37.7	37.7	36.0	35.9
Relative control (without nitrogen)							37.9
Absolute control (without fertilizers)							22.7

[a]Basic fertilization: 80 kg P_2O_5 and 40 kg K_2O/ha; sources: Urea, simple superphosphate, and potassium chloride;
[b]E_1 = full in planting furrow; E_2 = 1/2 planting furrow + 1/2 at 60 days; E_3 = 1/3 planting furrow + 2/3 at 60 days; E_4 = 1/2 at 30 days + 1/2 at 90 days; E_5 = 1/3 at 30 days + 1/3 at 90 days + 1/3 at 150 days; and E_6 = full dose banded at 60 days.

Table 8. Average root yield of cassava cv. BGM-001 as affected by levels and methods of application of P, CNPMF 1977/1978 (first year planting).

P_2O_5 (kg/ha)[a]	Application methods			Average
	Broadcast (total)	Broadcast (1/2 dose)	Planting furrow (1/3 dose)	
40	32.1	32.6	40.3	35.0
80	38.6	26.8	37.7	34.4
120	42.6	33.4	38.2	38.1
160	41.7	45.5	39.3	42.2
240	41.7	39.0	40.7	40.5
320	40.9	39.1	39.0	39.7
Average	39.6	36.1	39.2	38.3
Relative control (without phosphorus)			34.8	
Absolute control (without fertilizers)			22.7	

[a]Basic fertilization: 60 kg N and 40 kg K_2O/ha; sources: urea, triple superphosphate, and potassium sulfate.

Results in the first year showed no responses to different levels or application times of N (Table 7). Similar results were obtained in the second year, although yields declined.

Phosphorus fertilization was studied by applying triple superphosphate at six different levels (40, 80, 120, 160, 240, and 320 kg/ha of P_2O_5) and by using various application methods (Table 8).

During the first year there was an increase in root yield as the P doses increased up to about 160 kg P_2O_5/ha. No significant differences were observed among application times. Thus, the application of all of the P broadcast and incorporated gave essentially the same yield as the application of 1/3 of the dosage in the planting furrow. Although, yields were lower in the second year, there were significant differences among levels of P and methods of application. The yearly application of 1/3 of the P dosage produced 26.4 t/ha compared with 21.1 t/ha when all P was applied broadcast in the first year. The latter was not significantly different from the P control that yielded 20.9 t/ha.

To determine the critical level of P in the soil, four levels of P corresponding to 0, 80, 160, and 240 kg P_2O_5/ha were applied as simple superphosphate to obtain four different levels of P in the soil. Thus, the effect of soil P on the response of cassava to P applications can be determined in subsequent trials, by conducting separate P-response trials in each of the four P blocks. During the second year of planting in the four main P plots, there was a negative response to the application of 160 and 240 kg P_2O_5/ha. This yield decline may be due to P-induced Zn deficiency, as Zn levels in upper leaves during the first year decreased from 67 to 44 ppm with the high applications of P, and Zn deficiency symptoms were observed in the second year.

An experiment on levels, methods, and times of application of K was carried out with four potassium levels (40, 80, 120, and 160 kg/ha K_2O) applied as KCl, four methods, and three times of application. In the first year there was a slight response to the application of 40–80 kg/ha K_2O. Among application methods, best yields were obtained with side banding the fertilizer. Fractionation of K had no beneficial effect (Table 9).

In the second year, treatments with different application times were changed to annual broadcast or planting furrow applications. Responses to K application (40 kg K_2O/ha) were greater in the second year, while side banding was superior to broadcasting or application in the planting furrow. Annual application of K resulted in higher yields than one single application in the first year (Table 10).

Responses in top growth to P and K were similar to those in root yield, and both tend to increase in subsequent years of cropping the same soil. Fertilization was not found to have a significant effect on starch content. Increases in starch yield were thus directly related to increases in root yields.

Conclusions

Research on fertilization has shown that cassava is able to develop and yield in low fertility soils. However, to reach maximum production potential, adequate fertilization is needed. Phosphorus is the most important macronutrient for obtaining yield increases. Zinc was found to be the micronutrient most limiting yield, especially in highly limed soils.

Positive responses to nitrogen and potassium fertilizations are rare and generally not great although these elements are absorbed by the

Table 9. Average root yields of cassava cv. BGM-001 as affected by levels, methods, and times of application of K, CNPMF 1977/78 (first planting).

	Methods and application periods					
K_2O (kg/ha)[a]	Broad-cast	Planting furrow	Side-banded	Planting furrow (E_1)[b]	Planting furrow (E_2)[c]	Average
40	37.6	40.8	40.9	39.6	40.5	39.9
80	40.8	40.7	42.6	45.0	39.2	41.7
120	39.3	40.8	43.1	40.6	40.3	40.8
160	41.3	38.2	43.4	41.6	42.4	41.4
Average	39.8	40.1	42.5	41.7	40.6	40.9
Relative control (without potassium)						36.0
Absolute control (without fertilizers)						22.7

[a]Basic fertilization: 60 kg N and 80 kg P_2O_5/ha; sources: urea, simple superphosphate, and potassium chloride.
[b]Planting furrow E_1 = 1/2 dose at planting + 1/2 at 90 days.
[c]Planting furrow E_2 = 1/3 dose at planting + 1/3 at 30 days + 1/3 at 90 days.

Table 10. Average root yield of cassava cv. BGM-001 as affected by levels and methods of application of K, CNPMF 1978/79 (second planting).

	Method and application periods					
K_2O (kg/ha)[a]	Broadcast	Planting furrow	Side-banded	Broadcast annually	Planting furrow annually	Average
40	21.6	23.7	25.6	25.9	27.8	24.9
80	20.5	20.8	24.7	31.0	27.1	24.8
120	21.1	26.6	26.8	29.5	31.9	27.2
160	19.7	28.5	31.8	32.9	28.9	28.4
Average	20.7	24.9	27.2	29.8	28.9	26.3
Relative control						15.1
Absolute control						16.3

[a]Basic fertilization: 60 kg N and 80 kg of P_2O_5/ha; sources: urea, simple superphosphate, and KCl.

plant in larger quantities. Because phosphorus responses often increase with N and K applications and roots and tops remove large quantities of these elements from the field, it is recommended that these elements be applied in small quantities to prevent soil depletion.

Significant yield increases have not been obtained with liming. If necessary, liming should be carried out mainly to meet the nutritional requirement of the plant for Ca and Mg.

In view of the results obtained, research on the following aspects should be stressed: (1) studies on phosphorus sources and improvements for agronomic efficiency; (2) lime × micronutrient interaction, mainly zinc and manganese; (3) phosphorus × zinc interaction; (4) selection of cultivars with tolerance to high levels of acidity and low levels of available phosphorus; (5) basic plant nutrition research to determine the reasons for the inconsistency in nitrogen and potassium responses; (6) studies to determine the long-term effect of cropping on soil fertility and on N and K responses; and (7) the effect of crop rotation, mainly with legumes.

Although the aforementioned aspects are being studied, special attention should be given to the northeastern part of Brazil and the Cerrado region.

Chemical Weed Control in Cassava

José Eduardo Borges de Carvalho[1]

It is known that cassava yields are affected by weed competition for nutrients, light, and water. This competition is critical during the first 3 months after planting and before formation of foliage and roots. New weed-control techniques should be used to minimize yield losses, mainly in large-scale plantations where the use of preemergent herbicides is the most feasible method.

In spite of the relatively small number of studies on chemical weed control for cassava in Brazil, there is confidence in the results obtained with some components of the substituted urea group and their mixture with Alachlor in the many different ecological regions of the country. It may be possible to generalize the data obtained with Diuron, Fluometuron, Linuron, and their mixture with Alachlor in different dosages depending on soil texture and organic matter content.

Yields are affected by weed competition for nutrients, light, and water but little research has been conducted in Brazil on chemical weed control in cassava. This paper presents the information that is available and, based upon the analysis of the results obtained, provides some general recommendations for the use of herbicides as well as suggesting new methodologies for this field of research.

Herbicide Use in Cassava

Coelho and Correa (1966) carried out research in Sete Lagoas, Minas Gerais, using Diuron, Simazin, and EPTC in three different doses and observed that neither Diuron (2–4–6 kg a.i./ha) nor EPTC doses caused symptoms of cassava plant toxicity. Simazin produced plant toxicity in the three doses studied. EPTC did not control leafy weeds. In 1971 the same authors again tested several herbicides from the urea group in a red-yellow oxisol in Cerrado, Sete Lagoas, Minas Gerais. The authors determined that all the herbicides made first weeding unnecessary, and that Linuron, Diuron, Metobromuron, and Cloroxuron were the best ones because they presented residual effects in the soil for 70 days, replacing two manual weedings (Table 1).

Albuquerque (1971) pointed out that products with Triazin (Gesatop and Gesaprim) and Molinate (Ordram) cause cassava plant toxicity. At the same time he showed that Diuron was promising for the environmental conditions of the Amazon estuary.

Coelho et al. (1973) studied the effect of Diuron and Linuron (2–4–6 kg a.i./ha) on a dark-red oxisol of clay-like texture. Results are presented in Table 2. These authors concluded that under the conditions studied, Diuron and Linuron in the dosages tested did not affect cassava branch and root production, did not efficiently control *Digitaria sanguinalis,* but did control dicotyledonous weeds. It was also observed that the culture did not show toxicity symptoms under the dosages studied, and did not have reduced stand.

Santos et al. (1973) observed that Diuron and Fluometuron in doses of 2.5 kg a.i./ha were efficient for controlling *Richardia brasiliensis.* In reference to other weeds, control remained below 70%. Karbutilate in the dosages tested was highly efficient in overall weed control (rates higher than 99%). Diuron and Fluometuron provided only a 66% control at the larger doses (Table 3). They concluded that Karbutilate was better than the other herbicides and that none of the herbicides affected cassava production.

Cunha et al. (1975) tested the effects of Atrazin, Ametrin, Simazin, Diuron (Exp. 1) and Ametrin Simazin and Ametrin + Simazin (Exp. 2). A high number of chlorotic plants

[1]Agricultural Engineer, Scientist, EMBRAPA, Centro Nacional de Pesquisa Mandioca e Fruticultura.

Table 1. Weed control and production of roots and branches. Percentage of four replications.

Treatment	Active ingredient (kg/ha)	Weed dry weight ($g/2\ m^2$) 30 days	70 days	Production (t/ha) Roots	Branches
Diuron	2	10.0a	66.3a	15.0ab	27.1a
Fluometuron	2	21.5a	204.0b	8.6bc	16.3ab
Linuron	2	10.0a	39.5a	19.7a	30.2a
Chloroxuron	3	16.8a	80.0a	11.6abc	19.8ab
Metobromuron	3	10.0a	64.3a	17.7a	22.0ab
Control without weeding	—	95.3b	429.8b	6.3c	8.8b
Control with weeding	—	—	—	15.8ab	23.6a

Percentages followed by the same letter are not significantly different at $p = 0.05$ (Tukey test).

under all treatments were found in experiment 1. Plant death was observed in plots treated with Atrazin. In general, a negative influence of the triazin group over the growth and development of cassava was observed. In experiment 2, cassava death was not registered, though some crop toxicity was found.

Carvalho et al. (1977/78), based on the evaluation of herbicide effect on cassava, weed control, and yield (Table 4), found that Alachlor did not have a lasting effect when used alone and that the best treatments for the climatic and soil conditions of Cruz das Almas were: Diuron + Alachlor (1.0 + 1.5 kg a.i./ha); Fluometuron (3.0 kg a.i./ha), Diuron (1.0 kg a.i./ha), Alachlor + Fluometuron (1.5 + 2.0 kg a.i./ha); and Fluometuron (1.5 kg a.i./ha). The best treatments replaced two manual weedings.

The main weeds controlled were: *Ageratum conyzoides, Acanthospermum australe, Centrathrium violaceum, Cenchrus equinatus, Mollugo verticillata, Bidens pilosa, Acanthospermum hispidum, Amaranthus viridis, Lida* sp., and *Eleusine indica.*

Carvalho (1978) in Cruz das Almas, Bahía, studied the use of Diuron + Alachlor (1.0 + 1.5 kg a.i./ha) in recently pruned cassava plantations and concluded that this method for controlling reinfestation of weeds is feasible because: symptoms of toxicity to cassava were not severe and not observed 40 days after application; inhibition of sprouting was not recorded; and control percentages of 78% were still found 120 days after application. The main weeds existing were: *Commelina* sp., *Cenchrus equinatus, Ageratum conyzoides, Bidens pilosa, Acanthospermum hispidum,* and *Centrathrium violaceum.*

Carvalho et al. (1977/78) conducted studies in Cruz das Almas, Bahía, to check the selectivity of some herbicides (Chlorbromuron, Metolachlor, Fluometuron, Metribuizin, Sulfodiazol, and Oxifluorfen) used alone or in mixtures and concluded that except for Sulfodiazol, other treatments showed good results with respect to weed control, cassava selectivity, and yield.

Ternes and Ishy (1978) suggested the use of a mixture of Diuron and Alachlor in the following doses (kg a.i./ha): in clayish textured soils 1.60 Diuron and 1.29 Alachlor; in sandy clay soils 1.20 Diuron and 1.08 Alachlor; and in sandy soils 0.80 Diuron and 0.86 Alachlor.

Alcantara (personal communication 1979) studied Alachlor, Diuron, Fluometuron, Linuron, and mixtures of Diuron, Fluometuron, and Linuron with Alachlor in three doses of each.

Outstanding weed control was obtained for up to 90 days with Diuron application in doses of 2.5, 3.0, and 3.5 kg of commercial product (CP) per hectare. This was followed by: Fluometuron at 3.5 kg CP/ha; Linuron at 4.0 and 4.5 kg CP/ha; and the mixtures of Alachlor + Diuron at 2.75 l/ha + 1.25 kg CP/ha; Alachlor + Linuron at 2.5 l/ha + 1.75 kg CP/ha and 0.75 l/ha + 2.0 kg CP/ha; and Alachlor + Fluometuron at 2.5 l/ha + 1.25 kg CP/ha.

The main weeds controlled were: *Sida* sp., *Acanthospermum australe, Richardia brasiliensis, Portulaca oleracea, Cenchrus equinatus,* and *Melinis minutiflora.*

Silva et al. (1979) studied the performance of some herbicides in the Ponte Nova site in Minas Gerais. The doses of the products were 3.0 kg a.i./ha when used alone, with the exception of 2,4–D (2.0 l/ha), and half this concentration of each when used in mixtures.

Based on these results, the authors concluded: (1) the best weed-control treatments used Orizalina (Surflan), Diuron + Devrinol incorporated, Diuron + 2,4–D, Diuron + Cotoran, and Cotoran; (2) the greatest fresh root production was obtained with Diuron + Surflan, Diuron + Cotoran, Diuron + 2,4–D, and with weeding; (3) the best treatments for cassava branch pro-

Table 2. Average of weed control and weight of cassava branches and roots.

Treatments	Active ingredient (kg/ha)	Weed control average			Final stand (mean)	Branch weight (kg/ha)	Root yield (kg/ha)
		Digitaria sanguinalis	Dicotyledonous	Overall weed control			
Diuron	2	4.36a	4.84ab	6.56ab	15.5a	17.2a	13.2a
Diuron	4	4.16a	3.23ab	4.61ab	21.3a	23.3a	13.5a
Diuron	6	2.65a	2.43a	3.62a	18.3a	17.9a	10.4a
Linuron	2	5.06a	4.72ab	7.15ab	14.3a	16.1a	12.5a
Linuron	4	4.32a	3.94ab	6.16ab	16.3a	18.6a	11.8a
Linuron	6	4.14a	2.08a	4.79ab	19.0a	24.4a	12.8a
Control	—	6.12a	6.23c	8.78b	15.0a	16.8a	13.2a

Means followed by the same letter are not significantly different at $p = 0.05$ (Tukey test).

Table 3. Weed control percentage in preemergent trials, 30 days after application of herbicides and production of cassava roots (treatment: 21 September 1979; daily weed counting: 20 October 1971; harvest: 21 February 1973).

Herbicides	Active ingredient (kg/ha)	*Digitaria sanguinalis*	*Brachiaria plantaginea*	*Richardia brasiliensis*	*Sonchus oleraceus*	Overall control	Cassava root production (t)
Karbutilate	1.0	95.9	84.3	97.9	100.0	99.5	116.6
Karbutilate	2.0	99.6	99.3	100.0	100.0	99.9	98.8
Diuron	2.0	59.5	58.6	89.4	31.4	59.8	113.4
Diuron	2.5	62.8	76.0	100.0	54.3	65.7	96.2
Fluometuron	2.0	42.7	66.9	76.6	11.4	46.0	106.4
Fluometuron	2.5	65.2	69.4	94.0	50.1	66.5	100.6
Control (Number of weeds)		854	121	47	35	1057	93.2

Table 4. Production of fresh roots, aerial parts and starch (t/ha).

Treatment	Dose (kg a.i./ha)	Fresh roots	Aerial parts	Starch
A_1 (Diuron)	1.0	36.1b	25.6c	11.2a
A_2 (Diuron)	2.0	36.4b	17.6ab	11.3a
A_3 (Diuron)	3.0	22.5a	10.8a	6.9b
B_1 (Alachlor)	2.0	39.2b	19.0bc	12.2a
B_2 (Alachlor)	4.0	34.9b	17.5ab	11.0a
B_3 (Alachlor)	6.0	36.7b	17.2ab	11.2a
C_1 (Fluometuron)	1.5	35.1b	17.8ab	10.9a
C_2 (Fluometuron)	3.0	36.9b	18.5bc	11.5a
C_3 (Fluometuron)	4.5	36.3b	18.9bc	11.0a
A+B (Diuron+Alachlor)	1.0+1.5	38.3b	20.9bc	11.9a
B+C (Alachlor+Fluometuron)	1.5+2.0	35.1b	19.8bc	11.0a
T^1 (Control with weeding)	—	36.2b	20.6bc	11.1a
CV (%)		14.0	16.0	14.0

Treatments followed by the same letter are not significantly different at the $p = 0.05$ (Tukey test).

duction were Diuron + Devrinol, Diuron + Surflan, Ciuron + 2,4–D, Diuron, and weeding; and (4) Devrinol, incorporated, had the lowest overall weed control.

Final Considerations

In spite of the relatively small number of studies on chemical weed control for cassava in Brazil, there is a certain confidence in the results obtained with some components of the substitution urea group and their mixtures with Alachlor, in the different ecological regions of the country. This fact shows the possibility of generalizing the data obtained with Diuron, Fluometuron, Linuron, and their mixture with Alachlor. Thus, depending on soil texture, degree of organic material, and rainfall, the dosages (kg a.i./ha) could vary as follows: Diuron 1.0–3.0; Fluometuron 1.5–3.5; Linuron 1.5–3.0; Diuron + Alachlor 0.8–1.5 + 1.0–3.0; Fluometuron + Alachlor 1.0–2.0 + 1.0–3.0; and Linuron + Alachlor 1.5–2.0 + 1.0–3.0.

It would be interesting to study other groups of herbicides in different Brazilian regions and different types of soils, as well as to integrate them with other control methods to choose the most economically feasible method of controlling weeds at the farm level.

Cultural Control of Weeds in Cassava

Dietrich E. Leihner[1]

Cultural weed control in cassava includes general practices to increase the competitive ability of the crop as well as specific weed control measures. Selected and chemically protected planting material should be planted vertically to ensure optimum early establishment. Planting densities can be increased above the normal to impose more competition on weeds and partly compensate for deficient weed control. Effective, long lasting weed control is achieved with legume green covers and competition with cassava is low if nonaggressive species are used. Mulches provide shorter duration weed control than perennial legumes but they are noncompeting, add organic matter, and preserve moisture. Cultural weed control is labour-intensive and may also be capital intensive if seed or cover materials have to be bought and transported. However, with local availability of seed or cover materials and use of family labour, no purchased inputs are necessary and cultural control of weeds becomes competitive in cost with chemical or manual weed control.

Cultural weed control is defined as any nonmechanical and nonchemical practice that helps to suppress weeds by increasing the competing ability of the crop. Practices that contribute to a good establishment and growth of the crop, such as selection of adapted varieties, use of high quality stakes, the right planting density, and plant protection will in most cases significantly favour cultural control (Doll 1977). With cassava, cultural weed control is difficult during the first 3–4 months because of its slow initial growth even if agronomic practices are at their best. However, supporting cultural measures such as the use of mulches, green covers, or intercrops are possible.

General Agronomic Practices

Quality of Planting Material and Planting Technique

There are several agronomic practices related to selection of planting material and planting techniques that strongly influence the initial vigour of cassava. Planting material should be cut only from the mature but not too lignified parts of the plant (middle and upper portion), at a stake length of at least 20 cm. A visual selection for healthiness and freeness from insect pests should be done and the planting material should be dipped in a fungicide-insecticide-micronutrient mixture (Lozano et al. 1977). While these practices ensure high quality and good early vigour of the planting material, the right planting technique is necessary so that this early vigour can be expressed. For rapid sprouting and growth, a vertical planting position is recommended because horizontal planting delays emergence and reduces total sprouting percentage (CIAT 1979).

Plant Type and Planting Density

Both plant type and planting density determine the number of days needed by cassava to reach complete ground cover. The more vigorous, early-branching, and leafy a plant type, the shorter will be the time to reach ground cover. Similarly at higher planting densities cassava will reach ground cover earlier than at lower densities.

To establish the cultural weed control potential of contrasting plant types and densities, a field trial was conducted at Caribia on the Colombian north coast. The vigorous cultivar MMEX 59 and nonvigorous MCOL 22 were planted at densities of 7500 and 15 000 plants/ha in three weed control levels.

The results (Fig. 1) indicate that vigorous varieties are less sensitive to deficiencies in weed

[1]Cultural Practices Specialist, Cassava Program, CIAT, Cali, Colombia.

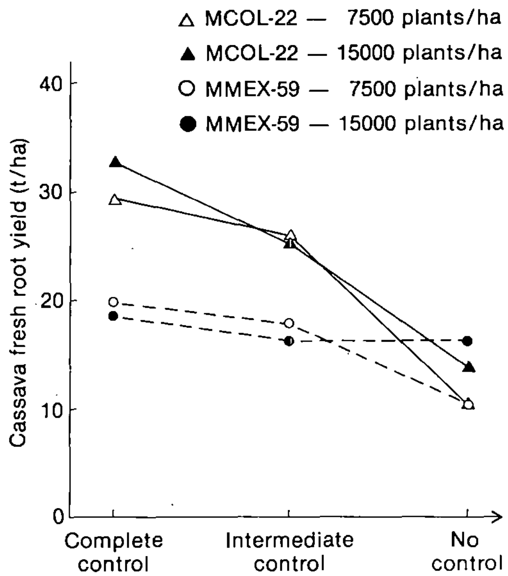

Fig. 1. Effect of plant type and plant population on cassava root yield at different weed control levels. MCOL-22 (nonvigorous) and MMEX-59 (vigorous) planted at ICA-Caribia, 1978–79.

control than nonvigorous varieties due to their greater competing ability. With good weed control (and other cultural practices), yield is largely determined by the particular yielding ability of a genotype; yield differences due to planting density are small. Under these favourable conditions, the yielding ability of the nonvigorous variety is not fully expressed at the low planting density, its yield response to a higher density is therefore positive. In contrast, the yielding ability of the vigorous cultivar is already expressed at the low planting density, its response to increased density is negative. A similar yield–density–plant type interaction is observed at the intermediate weed control level; however, the situation is different when weed control becomes deficient. Under these conditions, genotypic differences loose their influence on yield and higher plant populations as a means of cultural weed control gain importance. The yield increase from low to high planting density in the absence of weed control is up to 60%. It is concluded that if deficient weed control is anticipated, yield losses can be reduced by increasing planting density. Only as a second step should a change in variety be considered.

Soil Covers

Legume Green Covers

Green covers are planted with cassava for a variety of purposes. Cultural weed control, erosion control, fertility and moisture conservation, and forage production are among the most important reasons for this cultivation practice. CIAT (1979) reported planting of several leguminous cover crops simultaneously with cassava at CIAT Quilichao and Carimagua. The advantage of forage production and weed suppression in these trials was offset by strong competition from the legumes, which resulted in considerable cassava root yield reduction. Only cassava grown with *Stylosanthes guyanensis* at Carimagua showed no yield reduction. This was attributed to poor growth of stylo, which was seriously affected by anthracnose.

A system of planting cassava with stylo as a cover crop has also been reported from Bali (Nitis 1977; Nitis and Suarna 1977). Planting stylo between cassava produced cassava root yields similar to, or higher than, those obtained without stylo undersowing. The beneficial effect of stylo as a companion crop was attributed to an additional N-supply for the cassava, estimated to be equivalent to 20 kg urea/ha for unfertilized stylo and 160 kg urea/ha for fertilized stylo.

At CIAT, dry beans and *Desmodium heterophyllum* were used as cover crops under cassava. The leguminous forage species appeared particularly suitable due to its nonaggressive, prostrate growth habit. Both legumes provided a complete, permanent weed control throughout and beyond their growth cycle. When compared to mulching with cane bagasse, no significant yield difference was found between the two live covers and the dead one, indicating that competition for light, water, and nutrients in the cassava–legume systems may have been minimal. The absence of significant differences in root dry matter among the treatments further supports this view (Table 1).

Mulching

The weed-controlling effect of a cane bagasse mulch was similar to that of a preemergent herbicide mixture but not as long lasting as that of the legume green covers. However, control was sufficiently effective to avoid weed competition during the first critical months, as indicated by the good cassava yield obtained in this treatment (Table 1). Additional benefits of mulching are organic matter accumulation and moisture conservation benefits that the preemer-

Table 1. Effect of weed control systems on cassava (CMC-40) and bean yields and cassava root dry matter content (CIAT 1979).

Weed control system	Cassava: Dry matter (%)	Cassava: Fresh root yield (t/ha)	Legume yield (kg/ha)
No weed control	34.2	12.9	—
Preemergent herbicide	33.1	23.4	—
Cane bagasse mulch	33.8	27.6	—
Green cover (annual legume)	33.6	26.8	1.945[a]
Green cover (perennial legume)	34.2	26.9	600[b]
Manual weeding	33.6	33.2	—
C.V.(%)	2.5	13.6	
S.D.	0.86	2.97	

[a]Grain yield (14% H_2O) of black bean variety "Porillo Sintetico."
[b]Fresh forage material of *Desmodium heterophyllum* produced under cassava.

gent herbicide treatment could not provide. This explains the higher cassava yields obtained with mulching.

Intercropping with Grain Legumes

Cassava intercropping systems with different weed management practices have been studied at CIAT. During early growth, dry weight of weeds was lower in all treatments when cassava was intercropped with beans as compared to cassava monoculture. When weeds were not controlled at this stage, the sole introduction of beans as an intercrop was as efficient in reducing weed growth as was a preemergent herbicide mixture (0.5 kg a.i. Linuron and 2.5 kg a.i. Fluorodifen per hectare) in the corresponding cassava monoculture treatment. The "herbicide only" treatment was not different from the "herbicide plus hand weeding" treatment because hand weeding had not yet been carried out. At 90 days after planting, however, the difference between these two treatments was large, particularly in monocropped cassava, where the effect of the preemergent herbicide had been completely lost and weed infestation was high. In the "herbicide plus hand weeding" treatment the amount of weeds was small both with sole and intercropped cassava, a situation which was similarly observed in the "continuous handweeding" treatment due to the intensity of weeding. Without any weed control at all, beans as an intercrop were still able to reduce weed dry weight by 50% about 2 weeks before harvest. From further observations it was also concluded that intercropped beans had a residual weed control effect. In three out of four controlling systems, weed dry matter 135 days after planting (i.e. 30 days after bean harvest) was still notably inferior where cassava and beans had been growing in association as compared to cassava monoculture. Without mechanical or chemical weed control, cassava fresh root yield was 44% greater for cassava intercropped with beans than cassava monoculture, this yield advantage being largely attributable to the cultural weed control of the intercrop. With good weed control, intercropped cassava yielded 15% less than did the sole crop (Fig. 2). These data, besides confirming the general yield-stabilizing effect of intercropping,

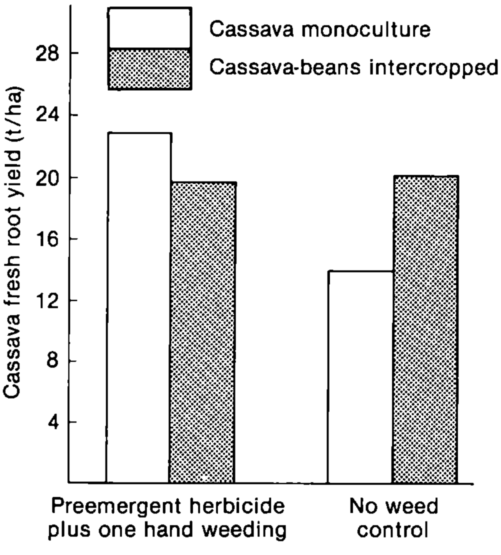

Fig. 2. Effect of two weed control levels on root yield in cassava monoculture and a cassava-bean association (CIAT 1978).

demonstrate that using fast-growing legume intercrops with cassava is an efficient practice for suppressing weed growth and that, with deficient weed control, greater cassava yields may be obtained through intercropping.

Comparative Cost of Weed Control Systems

Cassava gave the greatest yields when four manual weedings were done 22, 40, 60, and 115 days after planting. However, this was also the most expensive weed control system in terms of labour input (Table 2). Chemical weed control implied low labour expenses but elevated capital cost, whereas the use of legume green covers required high inputs of both labour and capital. Initial hand weeding during establishment required a few more man days for *D. heterophyllum* than for dry beans due to its slower ground covering rate. The high cost of seeds of both legumes explains the capital cost of these weed control systems. Mulching with sugarcane bagasse proved to be an interesting option, a low input level being needed in terms of both labour and capital. Even if a reasonable charge was made for transportation of the bagasse, the total cost for weed control would not be much greater than when using the herbicide mixture, the additional advantage of mulching being an 18% greater cassava yield and the ecological harmlessness of this cultural practice.

The data indicate that chemical control alone is competitive in terms of total weeding cost, but with the present product mixture the period of effective control is too short and additional hand weeding is necessary. The two types of legume green covers were very effective but they still required some initial hand weeding for establishment. They are nevertheless a valid option considering the possibilities of producing the seed material locally to reduce capital cost and obtaining additional income from grain legume production. Although no grain production is obtained from the perennial legume, it does provide other benefits such as long lasting cover, erosion control, N fixation, and 600 kg/ha of forage material at the time of cassava harvest. Mulching is an effective and low-cost practice, but its adoption depends on the availability of raw material.

Conclusions

The cultural weed control measures discussed in this paper have several disadvantages and advantages in common. Cultural weed control by such measures as the establishment of green covers or intercropping is labour intensive because it requires the establishment of two crops at a time instead of one. Overall weed control may, with the exception of specific cases, not be as efficient as it could be with chemical control. The requirement of timeliness, a particularly critical aspect of weed control in cassava, may sometimes not be fulfilled to the extent it is with mechanical or chemical methods. However, cultural weed control is always ecologically sound. Depending on the method adopted, and local availability of materials, it can also be of low cost in terms of purchase inputs. In addition,

Table 2. Cost of manual, chemical, and cultural weed control in cassava (CMC-40) in six weed control systems (CIAT 1979).

Weed control system	No. of hand weedings	Cost of weed control/ha Labour (U.S.$)[a]	Capital (U.S.$)
No weed control	—	—	—
Preemergent herbicide[b]	—	4.50	47.70
Mulch (cane bagasse)[c]	—	27.30	7.70
Green cover (annual legume)[d]	2	113.60	150.00
Green cover (perennial legume)[e]	2	131.80	60.00
Manual weeding (clean weeded check)[f]	4	218.20	—

[a]Colombian prices converted at a rate of U.S.$1 per 44.00 Colombian pesos.
[b]Linuron and Fluorodifen at a rate of 1 kg and 7 litres commercial product per hectare. One man day/ha for application.
[c]Cane bagasse at a rate of 17 t/ha. Six man days for application. Cost of raw material – $0.45/t. Transportation cost not considered.
[d]Black beans intercropped at a seed rate of 120 kg/ha with a cost of U.S.$1.25/kg seed. Twenty-five man days for initial weeding.
[e]*Desmodium heterophyllum* intersown at a seed rate of 4 kg/ha. Estimated cost of seed U.S.$15/kg. Twenty-nine man days for initial weeding.
[f]Forty-eight man days for manual weeding.

when fast maturing grain legume intercrops are used, an early income is obtained long before cassava is harvested.

The possibilities to combine cultural control with other weed control measures are numerous and provide the small farmer with a variety of choices where either labour or capital intensive practices are emphasized. This adds great flexibility to weed management enabling the farmer to adopt the weed control system that best fits his means and thus obtain satisfactory results both in terms of production and economics.

Integrated Control of Diseases and Pests of Cassava

J.C. Lozano and A.C. Bellotti[1]

Yield stability in any crop is dependent upon the use of ecologically adapted varieties, the employment of appropriate agronomic or cultural practices, and a sound integrated control program for diseases and pests. Because cassava has a long vegetative cycle, is propagated using stakes, and is cultivated primarily under traditional agricultural systems, it is important that an integrated pest-control program be based on cultural practices, biological control, and varietal resistance.

There are numerous cultural practices that aid in the control of insects and diseases. Uniform cultural practices cannot be recommended across all cassava growing areas; they should be adapted to the specific characteristics of each ecosystem. Some cultural practices that can reduce pest and disease stress include proper soil preparation, the use of clean, high-quality planting material, good weed control, removal and destruction of infected plant material and plant debris, crop rotation, intercropping cassava with other crops, well planned spacing of plants, proper fertilization, and strict quarantine regulations.

The long production cycle of cassava makes chemical control of pests uneconomical. An integrated control program should include sound biological control practices and the use of resistant varieties. An inventory of beneficial insects and microorganisms of cassava pests should be made. Programs for the mass rearing and release of beneficial insects or the introduction of new, more beneficial species should be initiated. The utilization of varieties resistant to the negative production factors of a given ecosystem is important in the control of pests and diseases and will ensure yield stability and satisfactory production.

Most agricultural research is directed toward the investigation of a specific factor or set of factors related to the production system of different crop species. The results of this research are rarely integrated in a logistic production package. More recently, research has been oriented on a commodity basis, making the integration of scientific teams to study one crop appear more reasonable; thus scientists can develop broader concepts of the crop and its problems, leading to more applied results.

With regard to cassava, there are several reasons why an integrated control program for diseases and pests is a prerequisite for yield stabilization and satisfactory production. Among these are the following:

(1) Cassava is a perennial crop with undetermined physiological maturity (Jennings 1976); consequently, an established biotic problem could be perpetuated.

(2) The vegetative cycle is long, ranging from 8–24 months, depending on the cultivar and/or ecosystem. During this time, the plants can suffer climatic and edaphic pressures (e.g. drought, low or high temperatures, nutritional deficiencies or toxicities), as well as attack by pathogens, insects, mites, and nematodes. The intensity and severity of these stresses vary among ecosystems and from one growing season to another and are related to the ecological conditions occurring throughout each growing cycle and to the existence of material susceptible to the stresses present.

(3) Cassava is propagated vegetatively from stakes obtained from lignified stems. The quality of the planting material is determined by the climatic, edaphic, pathological, and entomological stresses (negative production factors, NPFs) of the genotypes cultivated in a given cycle and their resistance to these stresses. The quality of the stakes determines, to a great extent, the overall success in achieving optimal yields (CIAT 1979, 1980; Lozano et al. 1977). On the other hand, infected and/or infested propagation

[1]Pathologist and Entomologist, Cassava Program, CIAT, Cali, Colombia.

material is highly probable in cassava unless preventive measures are taken (Lozano 1977a).

(4) *Manihot esculenta* is composed of cultivated clones that have been selected for desirable characteristics over many years by farmers in each ecosystem, primarily based on tolerance to the NPFs existing in a given region. The introduction of one or several NPFs from other ecosystems and/or planting clones in ecosystems different from the native one can cause serious damage to the original clones, as well as to those planted outside their native ecosystem (Lozano et al. 1980).

(5) Several cassava clones are planted in each region throughout the whole or most of the year. Consequently, in most ecosystems, tissues of diverse genotypes susceptible to different biotic problems are present throughout the year. The reason for the lack of epiphytotics in traditional plantations or for the presence of biotic problems at levels below the economic threshold is due almost entirely to the biological balance that exists in the ecosystem, and this must be maintained.

(6) Cassava has a long genetic cycle (up to 3 years), which delays the development of new, improved varieties, tolerant to specific problems (Kawano et al. 1978), thus a stable-type resistance is preferred.

(7) Cassava growers need to exercise great care in the production of their own planting material to avoid sanitary, agronomic, and economic problems caused by: (a) the low multiplication rate (5–10 stakes/plant) (Lozano et al. 1977); (b) damage caused to stakes because they are easily injured during preparation and transportation, as well as the difficulty of subsequent storage (40% of the buds in some clones failed to sprout after only 2 weeks' storage) (Lozano et al. 1977); and (c) packing and shipment of stakes, which is difficult and expensive because of their weight and volume (10 000 stakes required to plant 1 ha weigh about 1 t and occupy 2 m^3).

(8) Most cassava farmers are traditional farmers (Phillips 1974) with little technical know-how and few economic resources. Problems related to this crop should be solved using a simple, inexpensive but efficient cultivation system.

Based on the foregoing factors, the importance of integrated crop management in the control of pests and diseases can be seen. This system must combine good cultural practices with biological control and varietal resistance.

Cultural Practices

Uniform cultural practices cannot be recommended across all cassava-growing areas; they should be adapted to the specific characteristics of each ecosystem. Moreover, the incorporation of different practices should be based on a cost-benefit analysis, bearing in mind the farmer's capacity and that stability of production is the ultimate goal. Some practices may appear unessential, but the roots (the commercial product) may be affected and, unfortunately, this can be appreciated only at harvesting time.

The following are some cultural practices that, when applied in combination, can reduce or even eliminate stresses due to NPFs in a given ecosystem, thus producing stable yields.

(1) When cassava is planted immediately after the removal of forest, perennial or woody annual crops, severe root-rot problems can appear due to pathogens and/or pests that affect these plant species as well as cassava (Booth 1977; Bellotti and Schoonhoven 1978b). A decrease in soil infestation can be obtained by planting nonsusceptible crop species (e.g. cereals) before cultivating cassava and burning the plant debris left on the ground (Booth 1978; Lozano and Terry 1977).

(2) Soil preparation should be as for any other traditional crop. As cassava is susceptible to flooding and to pathogens favoured by this condition (i.e. *Phytophthora* and *Pythium* spp.), soil drainage must be adequate for the quantity and distribution of rainfall in each ecosystem. For example, planting on ridges is recommended when rainfall is higher than 1200 mm/year. The size and depth of these ridges will vary in relation to soil texture and frequency of rainfall (Booth 1978; Lozano and Terry 1977; Oliveros et al. 1974).

(3) It is well known that the quality of planting material is crucial for the successful cultivation of any vegetatively propagated crop. This is one of the most important factors in any cassava production program, responsible not only for good crop stand and establishment (good rooting of stakes and bud sprouting), but also for the sanitary conditions of the crop and final yield (commercial roots/plant) per unit area per cycle (CIAT 1978, 1980; Lozano et al. 1977).

The quality of the stakes depends on certain agronomic characteristics (lignification, thickness related to each clone, size, number of nodes/stake, angle of cut, and degree of mechanical damage), sanitary conditions (free of systemic and localized pathogens, insects, and mites), and disinfestant and protectant treatments applied before planting or storage (Lozano et al. 1977).

In general, stakes should be taken from the healthiest plantations on the farm or in the region, selecting the most lignified portion of the stem from vigorous 8- to 15-month-old plants, and cutting the stem in pieces 20 cm long at a right angle. Any portion of the stem with signs of necrosis (discolorations), cankers, tumors, galls, galleries, and/or insect (scales, borers, etc.) or mite infestations must be eliminated. Infested or infected stakes can contaminate healthy ones during the storage period (Lozano et al. 1977; Vargas 1978).

Stakes must be treated with fungicides and insecticides for disinfestation, disinfection, and protection. Planting material should not be stored unless strictly necessary (CIAT 1979, 1980; Lozano et al. 1977).

(4) Stakes should be planted in accordance with the terrain; satisfactory root formation and distribution result from the position of the stake in the ground (Castro et al. 1976). Good root development leads to vigorous plants, which are more resistant to biotic problems and easier to harvest. This in turn can lead to less physiological and microbial deterioration during storage, which are enhanced by mechanical damage during harvesting (Booth 1976; Lozano et al. 1977).

Considerable losses in establishment due to the failure of rooting or bud sprouting can occur if planting is done during the hottest season of the year in areas with high average temperatures. This may be caused by the effect of soil temperature on horizontally planted stakes; when planted vertically or obliquely, air circulation cools down the extreme upper portion of the stake, reducing the effect of hot soils. It is necessary to bear in mind that the bud thermal inactivation point of most cultivars is 52.5°C (CIAT 1974); high temperatures can also damage the stake epidermis, causing openings suitable for the establishment of pests and pathogens.

(5) Good weed control is important because cassava is a poor competitive species (Doll 1978). Moreover, adequate weed control could reduce both pathogens and pest populations on other host species and also allow good air circulation between plants, increasing the rate of rainfall evaporation. This reduces the relative humidity for sufficient time to decrease the rate of establishment and propagation of some pathogens, insects and mites. However, certain weeds can serve as a host and food supply for beneficial insects, and their elimination would decrease their populations. Weed control must therefore be carried out with both these aims in mind. In large plantations, it may be wise to keep plots or bands of native weeds to help maintain a natural biological balance.

(6) Periodic inspections of plantations are highly recommended to: (a) determine the scale and timing of agronomic operations such as drainage, weed control, etc.; (b) remove plants or plant parts with initial infection or infestation symptoms of diseases (viruses, mycoplasma, etc.), insects (scales, shoot flies, etc.), and mites, which at the initial stages attack scattered plants in the stand. These plants should be removed from the area in plastic bags and burned to prevent the dissemination of these problems; and (c) forecast the commencement of epiphytotics caused by pathogens and insects, allowing appropriate control strategies to be planned and carried out at the most advantageous time. A full-time trained worker would be justified on farms of 15 ha or larger to carry out control of agrophytosanitary problems.

(7) Because the roots are highly perishable, as a result of both physiological and microbial deterioration (Lozano et al. 1977), it is suggested that planting and harvesting operations be programed according to marketing conditions. Similarly, because the incidence and severity of this deterioration are enhanced by mechanical damage, this should be minimized or avoided during harvesting, packing, and shipping (Booth 1978).

Recent research on fresh-root storage suggests that physiological deterioration is a biochemical process (Lozano et al. 1977; CIAT 1980) that can be controlled by pruning 2–3 weeks before harvest. Storage of roots in sealed plastic bags to prevent dehydration by keeping up the saturated relative humidity also gives good control. Microbial deterioration has been controlled by dipping the fresh roots in a fungicide solution (Lozano et al. 1977).

(8) Plant debris left on the ground after harvest can act as propagation media for pathogens and pests that can cause severe damage to cassava after successive plantings (larvae of Coleoptera; *Rosellinia* spp., *Armillariella* spp., etc.). The elimination, especially of stems and roots, can help maintain these root-rot problems at low levels for several planting periods (CIAT 1979; Lozano 1978b).

The determination of the percentage of root rot after each harvest, especially on soils rich in organic matter, helps determine whether crop rotation or fallowing is advisable.

In general, plots that have over 3% root rot at harvest require crop rotation or fallowing to decrease the inoculum potential of biotics infesting the soil. When crop rotation is planned, care should be taken in the choice of crops in the sequence, because several other crops are also attacked by cassava pathogens; cereals are a good choice (Lozano 1978b; Lozano and Booth 1974; Lozano and Terry 1977). On the other hand, cutworm pests of maize and sorghum can also attack young cassava plants. If these are present, it is necessary to apply poison baits or spray the soil with fungal or bacterial pathogens of these insects before planting (Bellotti and Schoonhoven 1978b).

(9) Planting time can affect pest and/or disease incidence. Periods that favour high multiplication rates of pathogens, especially wet periods in the tropics or cool seasons in semisubtropical areas, should be avoided (Lozano 1978b; Lozano and Terry 1977). By planting over several periods during several cycles, it is possible to determine the appropriate planting time for each ecosystem.

(10) Consecutive planting in the same or in different plots over long periods of time can induce a progressive increase in the inoculum potential of pathogens and pests, causing outbreaks of increasing severity with time. A delay in planting for a few months will lead to a decrease in the biotic problem. This can also be reduced by planting stakes of longer than usual length (0.40–0.50 m instead of 0.20 m) to obtain large plants with several buds in a short period of time; these will have a higher tolerance to biotic problems such as shoot flies (*Silba pendula*) than small plants obtained from short stakes.

(11) Cultivation of cassava in association with other crops has been reported to be responsible for the low incidence and severity of biotic problems in tropical cropping systems; traditionally managed farms combine this with planting multicolonal cassava plots. This system should be studied and maintained wherever possible, above all where cassava is used as a staple food. Sudden changes in production systems may bring about unexpected changes in the ecological equilibrium, which in the long-term are reflected in the balance existing with the native biological control of the ecosystems.

(12) Well-planned spacing of plants can prevent the formation of microclimates favourable for the propagation of diseases and pests, as well as decrease the spread of biotic problems within the stand (e.g. scale insects). An ideal spacing can be reached by decreasing plant populations per unit area or changing the planting system (i.e. two rows separated by only 0.5 m, followed by another two at 2 m distance). The effects of such methods should be evaluated according to each ecosystem and its soil fertility, the clone type, harvesting systems used, etc.

(13) Improvement of growth conditions for cassava by increasing the nutritional level of the soil and the water supply during critical growth periods facilitates vigorous plant development, which in turn produces a higher tolerance to the stresses exerted by the biotic problems within a given ecosystem. However, the use of these cultural practices, their levels, and frequency of application should be determined by economic analysis. In general, plots that are selected for the production of stakes should receive the best cultural and biological treatments.

(14) As several biotic problems are disseminated through vegetative and sexual propagation material, it is of great importance to establish and strictly observe quarantine regulations (Lozano 1977). In general it is suggested that only official institutions be authorized to introduce cassava propagation material; vegetative material should be introduced by meristem culture or sexual seeds taken only from healthy plantations.

(15) The use of sonic light traps, poison baits, pheromones, gamma and X rays for sterilization, hormones, etc. are control measures that should be considered to improve the control of insects during different periods of the crop cycle, taking into account the biotic problem, the ecosystem, and the feasibility of its execution (Bellotti and Schoonhoven 1977, 1978b; Bellotti et al. 1980).

Biological Control

The long production cycle of cassava makes chemical control of pests uneconomical. This fact, combined with the great ability of the cassava plant to recover from abiotic and biotic stresses, indicates that biological control may prove very effective (Bellotti and Schoonhoven 1978b; Bellotti et al. 1980). Moreover, many beneficial agents exist in cassava plantations: in the case of *Erinnyis ello* alone, some 30 parasites, predators, and pathogens have been identified (Bellotti et al. 1980). Biological control should constitute one of the most important approaches of any integrated control package for the diseases and pests of all ecosystems.

The following suggestions can help maintain the natural biological control already present in a given ecosystem and improve it by increasing populations of native or introduced beneficial agents.

(1) Although pesticides are valuable compo-

nents of integrated control, they must be used only when other control measures are not effective and when it is economically necessary because of yield reductions caused by the biotic problem (Bellotti et al. 1980; Lozano 1978a). If an outbreak requires pesticide application, this should be selective with, if possible, a low lethal effect on beneficial agents (Bellotti and Schoonhoven 1978a; Bellotti et al. 1980).

(2) A detailed inventory of beneficial insects and microorganisms as well as of pests, diseases, hosts, and food sources of these pests is urgently required. The evaluation of each biotic problem in each ecosystem will aid in the establishment of priorities for each approach to biological control.

(3) Ecological studies directed toward explaining the relationship between parasites, pests, and the environment will provide valuable information for future strategies on biological control for each ecosystem.

(4) Natural biological control can be improved by increasing the populations of the most beneficial species through mass rearing, followed by liberation and colonization (Bellotti et al. 1980). It can also be improved by the introduction of new, more efficient beneficial species or biotypes that can be adapted to the conditions of a particular ecosystem.

(5) Even though modern agriculture uses the monoculture/homogeneous genotype system for several crop species, our experiences with cassava lead us to suggest that it would be better to use the multivarietal system in monoculture or mixed cropping with other crop species, as is the current practice among most cassava growers. The genetic clonal variability in plantations restricts the asemic propagation of pests and pathogens, keeping their populations at low levels, greatly reducing the risk of sudden outbreaks.

(6) Alternate hosts of pathogens and pests, grown in or near cassava plantations (e.g. *Poinsettia pulcherrima*, host of the causal agent of superelongation disease), should be removed, as well as any source of food for pathogens and pests (the hornworm eats leaves of rubber trees; fruitflies feed on rotting fruits; several soil-borne pathogens live on decaying cassava root debris, etc.). Extension programs should explain the advantages of carrying out these practices and if hosts cannot be eliminated because of their economic importance (rubber trees in Malaysia and Brazil, for example), integrated control programs should also be planned for these crop species.

(7) The liberation of irradiated insects or interspecific hybrids of pests in the area has not yet been done in cassava, but would be a promising biological control system for the future. Spraying the soil with bacteria, fungi, viruses, etc. that are pathogenic to soil-borne insects and pathogens of cassava, is another good possibility that merits study.

Varietal Resistance

Yield stability with time in a given ecosystem is related to the stresses resulting from the NPFs existing in each ecosystem, as well as to the genetic capacity of clones to tolerate these stresses. Because cassava clones have been selected for a very long time in localized areas and perpetuated vegetatively, the cassava/ecosystem interaction is great. A good, well-adapted clone with tolerance to a given ecosystem could be severely affected by the NPFs of another ecosystem. Consequently, in each particular ecosystem, regional clones or clones from similar ecosystems should be preferred to those introduced from ecosystems with different sets of NPFs. Introductions should be made specifically to improve the gene pool existing in each ecosystem (regional clones). Improvement programs should be decentralized and located in areas selected on the basis of extensive agro-socioeconomic studies (Lozano et al. 1980).

The concept of varietal evaluations should be multiple, integrating the following three general concepts: (1) a satisfactory yield of fresh roots, starch, foliage, etc. according to its utilization; (2) a good production of high-quality planting material; and (3) a highly acceptable root quality according to the socioeconomic requirements in each region. Clones selected according to these criteria would probably be the most stable over time, being the most acceptable to farmers.

Clonal evaluation in each ecosystem should be directed to identifying genotypes with the widest type of resistance to the NPFs existing in it; this evaluation should be performed by observations in areas where the NPFs of each ecosystem are most severe and most frequent. These evaluations should be integrated, performed by scientists of different disciplines and during several consecutive cycles (CIAT 1978, 1979; Lozano et al. 1980). This should not eliminate or underrate evaluations directed to identifying tolerance to specific important biotic problems because this could be needed to improve clones having wide-type resistance but susceptible or deficient in certain required characteristics.

Varietal resistance obviously improves biological control of the area because economic damage occurs only at higher population levels, facilitating the increase of beneficial biotics and reducing or eliminating the need for pesticides. In cassava an attack of *Erinnyis* spp. can produce up to 40% defoliation without causing any yield loss; this permits a delayed insecticide application for their control or the use of any other control measure compatible with the biological equilibrium of the region.

The foregoing general recommendations for the integrated control of diseases and pests in cassava should be complemented by scientific support given by research and extension agencies to growers and processors. The long-term success of cassava production in a given country or region may depend on both the research support and the appropriate application of these control measures.

Mechanical Planting and Other Cassava Cultural Practices in Cuba

Adolfo Rodríguez Nodals[1]

Cassava production practices in Cuba are described with emphasis on mechanical planting and harvesting, and other cultural practices aimed at obtaining greater productivity. Mechanization is of great importance in Cuba due to a scarcity of agricultural labour. The main cultural practices in Cuba include: planting new high-yielding, well-adapted cultivars; selection of lignified 25–30 cm stakes from mature healthy plants; treating the stakes with fungicide; planting the stakes at an inclination of 45° on top of high (40 cm) ridges; application of fertilizer; irrigation as needed; and good weed control. The results and experience obtained with two mechanical planters and three mechanical harvesters are described.

Cassava is one of the most popular food crops in Cuba although it is not the most profusely cultivated. In 1977, cassava production reached approximately 90 200 t, which is a 182% increase over the level in 1967 (Table 1). However, the national average yields are very low (4–5 t/ha), and are in contrast with the high potential of the clones studied in the experimental stations of the country. Cassava has developed greatly in Cuba since 1978, when a series of agronomic surveys showed that with some changes in cultural practices and with the use of high potential clones, productivity greater than 45 t/ha could be obtained on a large scale.

Table 1. Yields, planted area, and cassava production in Cuba in 1976 and 1977 as compared to 1967.[a,b]

Year	Planted area (ha)	Production (t)	Yields t/ha)
1967	23 927	49 520	2.7
1976	19 284	92 092	3.8
1977	19 110	90 202	4.0

[a]Source: Report to the Third National Technical Meeting on Tropical Starchy Crops. Division of Crops, Ministry of Agriculture, Cuba.

[b]Production does not correspond to the planted area in the same year due to the crop cycle (1–12 months in Cuba). The numbers represent the planted area during the whole year and root production in tonnes from January to December of each year.

[1]Centro de Mejoramiento de Semillas Agamicas (CEMSA), Santo Domingo, Villa Clara, Cuba.

Mechanization is of great importance in Cuba because of the scarcity of labour for agriculture and the need for yield increases. Consequently, cassava development requires the following: clones that produce roots on the surface and in groups; the use of mechanically built ridges; mechanized planting; the use of herbicides; and propagation material free of disease. The cultural practices presently used in Cuba are being studied to look for possible ways to increase yields (to more than 45 t/ha) and at the same time obtain maximum savings in labour.

Cultural Practices

Use of Ridges

Maximum yields have been obtained when cassava is planted on ridges of a minimum height of 40 cm. It has been shown that the clones Señorita, Pinera, and CMC–40 are more productive when they are grown on top of the ridges, provided the stakes (25 cm long) are buried almost completely at an inclination of about 45°.

Experimental "records" for yields in Cuba of 104 t/ha/year for CMC–40 and 98 t/ha/year for Señorita have been established. The ridges are spaced at 1.2 m from the furrows to make earth placement easier. The greatest yields obtained with planting on flat lands with the same clones were no greater than 45 t/ha/year.

Planting Space

A spacing of 1.2 m between furrows means that a spacing of 0.7 m is required between the plants to maintain populations at approximately 12 000 plants/ha. Until 1979, the most commonly used planting space in Cuba was 90 × 90 cm (a little more than 12 000 plants/ha).

Planting

With planters able to plant stakes on top of the ridges at an inclination of 45°, mechanical planting is used more and more.

Two machines are used at present: one of them is in the experimental stage.

(1) *TR–4 Transplanter.* This Bulgarian manufactured machine can plant 3–5 units per planting and can be used with 28–48 h.p. tractors. It can be used for tobacco transplanting and has given good results when used as a cassava stake planter. The three-unit model can plant 1 ha in 8 h; the five-unit model can plant 1.6 ha in 8 h. According to the expertise of the workers, planting at 45° or any other angle of inclination can be obtained with this machine.

(2) *Planting "Batabano".* This type of machine is in the experimental stage. It has four units and can cut the stakes, open the furrows, add fertilizer, treat the stakes, and plant the stakes with the desired inclination. With this machine, 14 ha can be planted in 8 h.

Use of Herbicides

Diuron, used as a preemergent herbicide at a rate of approximately 1 kg a.i./ha, has shown the best results. Paraquat, as a postemergent, has been used with a protective shield in doses of about 0.75–1 kg of the product per hectare.

Harvest

Harvest requires a great number of man-days if manually done. Efforts are being made to harvest cassava semimechanically. In this respect, planting in ridges and the use of varieties that produce roots close to the stem have been very useful.

Three systems are used in harvesting:

(1) *A Remover.* This is a conveniently modified subsoiler, which has horizontal wings and is coupled to a 48–60 h.p. tractor. This machine harvests one ridge, working under the roots, removing the stalks, and forcing the roots up. It is only necessary to cut the roots to separate them from the stalk. Average yield is 3.6 ha/8 h and the tractor usually works at a speed of 5 km/h.

(2) *U.C. Harvester.* This harvester was designed at the Universidad Central de Villaclara, Cuba. It is a combine and harvests 18 plants simultaneously. However, it is necessary to link each plant to the device to harvest the plants. This results in yield losses and makes harvesting somewhat complex.

A 48 h.p. tractor is needed and the yield is 1 ha/8 h. It is necessary to previously cut the stalks and leave a 20 cm stump.

(3) *"Batanó" Harvester.* This harvester is in an experimental stage. It can harvest plants without previously collecting the stalks. This machine separates stalks from roots, which fall onto different conveyors. Thus rows of cut stalks and roots are separately left behind the machine. Yield is approximately 10 ha/8 h with a tractor of a minimum size of 48 h.p.

Conclusions

(1) During the last few years cassava has assumed greater importance in Cuba as a food crop because of its great production potential and the introduction of a wide range of more advanced cultural practices.

(2) Mechanization is highly stressed especially for planting and harvesting and some new planting and harvesting models are promising.

(3) Planting in ridges is rapidly replacing planting on the flat. Clones of a higher yield potential have doubled yields when used in combination with a system of ridges.

Cultural Practices for Large Cassava Plantations

Hélio Correa[1]

The development of the national alcohol program (PROALCOOL) in Brazil opened new perspectives for cassava production expansion with many socioeconomic benefits expected and some production problems to be solved. The frontier known as the Cerrado located in central Brazil was chosen for the site of the first cassava alcohol plant because of its underutilization and good geographic situation. This land represents about 17% of the total area of the country and is characterized by variable rainfall (from 80 to 1500 mm/year). Rainfall is higher between October and March. The soil, classified as an oxisol, has low pH and lacks nutrients, especially P. In general, the topography is excellent for mechanization. The first cassava alcohol plant was installed by PETROBRAS in 1976 in Curvelo, Minas Gerais, with a capacity of 60 000 l/ha. Large cassava plantations were needed to keep the plant operating 330 days a year; specifically enough planting material was needed so that 2000 ha could be cultivated the first year. Thus, the cassava producers brought stakes from all over the central and southern part of the country and in the process brought cassava bacterial blight (CBB) as well. This situation motivated research to find CBB-resistant varieties. Another problem that arose was infestation by pests, especially hornworm and lace bug. Agronomic practices including fertilization, stake selection and treatment, good weed control, and modification of plant densities to 16 000 plants/ha are helping to solve production problems. Heavy machinery is used in soil preparation from felling to disking, and mechanical planters and harvesters increase efficiency. In addition, high dosages of limestone and phosphorus are currently being added to the soil.

The selection of cassava as a raw material for fuel alcohol production brings as an immediate consequence the need to adapt the production of this crop to the requirements of the alcohol industry. Cassava has traditionally been used as a subsistence crop or as raw material for small- to medium-sized industries, and its production technology has remained simple. No investments have been made on inputs or equipment for it, because it has been produced for a poor and unsteady market. However, the development of the Programa Nacional do Alcool (PROALCOOL) (created in November 1974) produced new perspectives for cassava production. Alcohol production using sugarcane, cassava, or any other raw materials will be given incentive by expanding supplies. However, for cassava, the expansion of supply must occur without causing a reduction in any other crop; it must allow a better distribution of socioeconomic benefits; make use of areas with poor soils and erratic rainfall conditions; and expand the agricultural frontier by incorporating new areas into production, especially those soils under Cerrado-type vegetation.

With these constraints in mind, PETROBRAS constructed the first cassava alcohol plant in Curvelo, Minas Gerais. The plan was to use the process developed by the Instituto Nacional de Tecnología (INT). The construction of the plant gave impetus to several new activities, including the development and optimization of an industrial process using cassava for alcohol production; the large-scale production of cassava for the alcohol industry; and the incorporation of the Cerrado into the productive process. The problems that were encountered and the technology that is used by the large-scale producers are dealt with in this paper.

The Cerrado

The Cerrado constitutes a large portion of the area available for agricultural and forestry ac-

[1]Escola Superior de Agricultura de Lavras (ESAL), Lavras, Minas Gerais, Brazil.

tivities in central Brazil; in Minas Gerais, it is 308 000 km^2, or 53% of the state's total area. Located near large consuming centres, it is the most feasible area for expansion of the agricultural frontier.

Rainfall in the region varies from 80 to 1500 mm/year and is mostly between October and March, although during this time dry intervals called veranicos can last more than 20 days and be accompanied by high temperatures. The mean annual temperature is 20–24 °C, July and February being the coldest and hottest months, respectively.

According to the Köppen classification, the major climates of Brazil are tropical, humid (Aw) and temperate, rainy (Cwa). Soils are poor, but they are deep and have good texture. They are normally acid (pH 4.0–5.0), high in Al and Mn, and low in Ca, Mg, P, S, and micronutrients. In general, the topography is well suited for mechanization, as the land is slightly undulating.

The vegetation is characteristic of campo, cerrado, and cerradão soils, which are typical of large-scale plantations (often more than 2500 ha).

Soil Preparation

Soil preparation depends on whether or not the area is already under cultivation. For agricultural frontier expansion, it includes felling of trees; firewood utilization; windrowing; elimination of rows and withdrawing or burning of residues; lime application; deep subsoiling; heavy disking; erosion control practices; and final disking.

Felling of Trees

Felling involves overturning all woody material, the most appropriate equipment for the job simultaneously withdraws the roots. This work is better accomplished when it is not preceded by removal of the firewood, which causes detruncation and makes for very tedious work. The most common methods of felling use either a flat blade or chains. A tractor equipped with a flat blade is used in soils where vegetation is moderately dense. The tractor operator must be very careful to avoid removing the superficial layer of soil, which contains a large percentage of the organic matter. The flat blade helps in opening roads as well as other services but cannot be used to cut down big trees because its efficiency is low. Tractors used for this work must have a capacity of 70–140 h.p. Depending on the type of vegetation, one 140-h.p. tractor is able to clear 1 ha, in 1–2 h.

If the firewood is removed before felling, clearing time is increased considerably because the machinery is used for trunk pulling only — a less efficient operation.

The use of chains is very common in areas to be planted with cassava, especially when the areas are extensive. This method is more efficient for large areas than is the one using flat blades. Two or three tractors weighing more than 13 t with at least 140 h.p. are normally used. The chains are attached to the hitches of the tractors, which move in parallel lines at the same speed and carry the chain 30 cm above the ground. The chains weigh between 60 and 120 kg/m, and the length must be 2 or 3 times the width of the work strip — a factor dependent on the power of the tractors. For a distance of 30 m between tractors, the chain must be 60–90 m long. The curve provided by the chain improves the traction, and weights such as rail pieces or iron balls are attached to the chain so that it cannot pass over obstacles. Felling with chains is most efficient when two passes are made in opposite directions. The second pass is called arrepio.

Firewood Utilization

The removal of firewood or timber can be done before or after windrowing. Crosscut saws are used for cutting the trees; the wood pieces are taken to a wood deposit by tractor-pulled trailers. Service roads surrounding the plots make the execution of this type of work easier.

The quantity of wood depends on the previous use of the land. In dense cerrados, firewood yields of 50–60 m^2/ha are common and are used for charcoal production.

Initially it had been planned that this material would be used as an energy source for alcohol production, but the presence of different species hindered woodchipping machines and caused undesirable variations in steam production because of the different wood densities.

Once the wood has been collected, windrowing the remaining vegetation begins. The firewood that is obtained helps offset the costs of soil preparation.

Windrowing

The next step is to pile the plant material that is left on the ground. If the material is raked into even rows, the following operations are easier and less costly. Windrows are made by a frontal rake which does not remove the superficial layer of the soil. It is possible to use the flat blade when felling and windrowing are done at the same time, but great care is required. The distance between rows varies, but it must never be more than 60 m, as larger distances mean unnecessary movements of tractors and reduced efficiency.

Elimination of Rows

The elimination of rows is made initially by fire; then the unburned material is scattered by a tractor using a frontal rake. The scattered materials dry quickly and can then be burned. After this, all remaining roots and stems are removed.

Limestone Application

Cerrado soils are generally acid, and a limestone application is necessary. This can be done either before or after the disking operation. Liming is done with special spreaders that are attached to the power takeoff of the tractor. The equipment used for this operation has a capacity of more than 2 t and can lime 1 ha in approximately 30 minutes.

The limestone should be deposited in sites selected for ease in equipment loading, and the efficiency of the operation is improved when a 65-h.p. tractor equipped with a loader is used.

Usually, some yellowing can be observed in plants grown where the limestone was deposited due to pH modifications of the soil and the obstruction of micronutrient absorption.

Deep Subsoiling

Subsoiling is not a common practice in the region. It was adopted specifically to obtain better soil preparation for cassava production. A machine, called a subsoiler, is used; it has 3–4 tines, 60–70 cm long, 70–80 cm apart and is attached to the hydraulic system of a 140–200-h.p. tractor. The tines, which curve forward, are tied to the toolbar. Their function is to break up the soil and at the same time to pull out the roots that remain in the soil after felling.

To pull out the roots, the tractor must raise the subsoiler occasionally. The tractor stops and goes backward to release the roots, and the hydraulic system is activated to start the operation again. Removing the roots, which are usually numerous in cerrado soils, increases the soil's water retention and aeration as well as facilitating disking and planting. After the subsoiling, which generally takes 2 h/ha, it is necessary to collect all the roots that have been brought to the surface.

Heavy Disking

Harrowing produces a soil structure that allows good water retention, provides adequate air capacity and gas exchange, and facilitates future operations. Harrowing also cuts up any plant residues and promotes high yields. Depending on the weight of the harrow, the speed of the tractor, and the disk diameter, the depth varies from 20 to 30 cm.

A heavy plow is better than a harrow, especially in relation to root fragmentation, and soils prepared with heavy plows show a higher sprouting rate.

Generally, 12–20 disks, 28–36 inches (71–92 cm) in diameter, are used for heavy disking; cutout blade disks work best.

The efficiency of the harrow depends on the tractor used. With a Fiat AD 7, harrowing takes 2 h/ha; with a Fiat AD-14, 1.5 h/ha. Four-wheel drive, 300 h.p. tire-type tractors are also used. After disking is completed, any woody materials that have been brought to the surface are collected.

Erosion Control

Heavy disking is followed by measures to control erosion. Terraces are shaped by bulldozers and completed by a carrier-type scraper, which is more efficient. The fields have a mean area of 20 ha. Any conservation practices must be based on soil conditions, topography, and climatic data. Terrace distribution should be such that farmers do not have to drive over the terraces to have access to the field.

Final Disking

Final disking is done a few days before planting, and a 60–90-h.p. tractor with a harrow (32 × 20 inches) is generally used. The disking eliminates any sprouts and conditions soil for mechanized planting. If needed, phosphorus must be applied just before final disking so that it is incorporated in the soil but not as deeply as limestone.

In previously cultivated soils where limestone and, in some cases phosphorus have been applied, heavy disking and plowing are done first (if the appropriate machinery is available), and then, a few days before the cassava is planted, light disking is done.

Fields where the last crop was cassava must be cleared by a mechanical rake before plowing. This mechanical rake or windrower pulls together all plant material, which is later burned. A hectare can be cleaned with this equipment in 40–60 minutes, depending on the amount of plant material. If not cleared from the field, cassava residues produce irregular sprouting, which is a problem for future work.

Stake Selection

Stake selection is one of the most important steps in the establishment of a new culture. Branches must be subjected to phytosanitary controls and come from healthy cultures; 10–12-month-old branches are the best if they are mature, well developed, and 2–3 cm in diameter. Vigorous stakes with perfect buds produce healthy plants. Stakes must be mature because if they are not well lignified, they are more susceptible to insects, diseases, and adverse climatic conditions.

A practical way to determine the maturity of a plant is to compare the diameters of the pith and the stem. If the pith is smaller than 50% of the stem diameter, then the stake is at the recommended stage of maturity. The presence of pentagonal forms or foliate scars indicates that the material is immature.

Other precautions that must be taken involve protecting the stakes from mechanical damage during transportation, preparation, storage, and planting. Damaged stakes are more susceptible to microorganisms and are less likely to survive. Because insects and pathogens may be present in the stakes but not visible (bacteriosis), trained personnel must conduct the stake selection.

Stake Preparation

Once the branches have been selected, they must be cut. Usually they are cut 10–15 cm above the ground, the labourer using a machete or a motorized saw. Then, they are bundled together in groups of 50, tied with string, and stored away from direct sunlight. The mean branch yields vary with the cultivar, soil fertility, age, and spacing of the plants.

Stake Transportation

Transporting stakes from the field to where they are going to be planted or stored is done by trailer or truck. Stake bundles must be carefully arranged so that the buds are not damaged, and their drop off places at planting areas must be predetermined so that transportation costs and material handling are minimized.

Transportation must be completed as quickly as possible, especially if the cutting coincides with hot weather, because exposure of the buds to the sun's rays can lower sprouting percentages. When the stems are not in bundles, loading is difficult and time-consuming: to load a 50-m^3 capacity tractor takes 3–5 men/day; an 80-m^3 trailer needs 12 men/day. In contrast, loading a 50-m^3 truck with bundles takes 5 men 2 h.

Discharge at the storage place is done with the help of wood stakes and steel wire pulled by a tractor; it takes less than 15 minutes. Storing, however, requires 6 men/day.

A 20-m^3 truck has sufficient capacity to feed four Martins-type planters (whole stake) and to haul fertilizer if working within 3–4 km of the planting area.

Stake Preservation

In cassava cultivation, insects or diseases that might affect the stems after harvesting must be considered. Storage problems are of considerable importance in regions where the stakes must be preserved for use later as planting material. Stake preservation, no matter what method is used, causes dehydration and favours insect and disease attacks, especially among immature stakes. Thus, losses by dehydration and insects or diseases are related to the selection of stems.

Some chemical applications may prevent damage to the stakes during storage. Dithane M-45 (200 g/100 l water) in a mixture with insecticides is recommended. In large-scale plantations the treatment is done while the stems are in storage. Sometimes stored stakes harbour *Diploidea manihotis*, which causes plant death a few weeks after planting. The symptons are lodging, rot, and vessel darkening.

When storage is necessary, the stems must be bundled, placed in the shade in a vertical position, their base covered with moist, loose soil and grass as protection against dehydration. Shoots that emerge at the apical end and small roots at the base are eliminated at planting. Storage varies from 30 to 60 days, and all data show that losses are in direct relation to storage time. In large-scale plantations it is recommended that the stems be distributed throughout the field, with their bases slightly buried in the soil and the sides and top covered with palm tree leaves or grass (Fig. 1). Losses up to 30% have been reported.

Storing stems horizontally in warm areas such as Felixlândia (Minas Gerais) is not recommended for more than 30 days, because sprouting begins and the buds can be easily damaged.

Preparation of Stakes

The establishment of a cassava plantation requires very special attention of the stake preparation step because productivity is based on selection and manipulation of planting material.

Cutting stakes horizontally is recommended because a slanted cut increases tissue exposure and dehydration. The operation should not take place in direct sunlight, especially if the stakes are being cut from stems that have been stored. Two men using a circular saw powered by an electric, gasoline, or diesel motor can cut 50 000–60 000 stakes a day; two more men are required for selection and packing (Fig. 2). Working together, they can supply enough planting material for a Sans planter operating 11 h/day. When the stakes are to be 20 cm long, they should be cut 1–2 cm longer as compensation for losses due to the cutting operation. After being cut, the stakes are placed in plastic boxes that hold 250–300 stakes.

When stakes are transported, the trailers and turcks must be covered, and once the boxes are discharged at the planting sites, they must be covered on sunny days.

Planting the Stakes

The equipment available in Brazil for mechanized planting only allows horizontal planting of the stakes, which are 20 cm long. When the soil is dry, the planting depth is increased so that the stakes do not become dehydrated. The mean planting depth in large-scale plantations is about 10 cm.

Adding Lime, Phosphorus, and Fertilizer

Limestone is needed in the cerrado soils, but how much is still uncertain because the amount varies with different cultures and soils. Data on the effects of lime on cassava are contradictory, possibly because of the lack of detailed studies on the interactions of lime × zinc, lime × phosphorus, and lime × phosphorus × zinc. At present, the quantity of limestone to be applied is

Fig. 1. The system used for stem storage in Minas Gerais, Brazil.

Table 1. Fertilizer recommendations for Minas Gerais.

	Soil analysis (ppm)		Fertilizer (kg/ha)		
Soil texture	P	K	N	P_2O_5	K_2O
Loamy and Sandy	0–10	0–30	30	90	90
	11–20	31–60	30	60	60
	20	60	30	30	30
Clayey	0–5	—	30	90	—
	6–10	—	30	60	—
	10	—	30	30	—

calculated on the basis of interchangeable Al and Ca + Mg meq/100 g of soil.

In general, in areas that have just been cleared, 2–3 t/ha of lime are applied. Dolomitic or Mg-rich lime is rarely used because of high costs. It is possible that these rates are not the best for cassava plantations, but they are used in anticipation of future uses of the land, especially crop rotation. Limestone is applied to a depth of 20–30 cm at least 10 days before planting.

Application of phosphorus, called corrective fertilization, is recommended for soils with phosphorus levels lower than 5 ppm; recommended doses of P_2O_5 are 100, 150, and 250 kg/ha for sandy, silty, and clayey soils, respectively.

Phosphorus fertilizers, preferably thermophosphates with micronutrients, are broadcast and incorporated with a light disking to a depth of 0–10 cm. This operation allows better utilization of the P_2O_5 applied to the rows. Even though phosphate application is recommended, it is not widely practiced because of its high costs.

Table 1 shows the fertilization schedule for the state of Minas Gerais. As no adequate method exists for determining available N in the soil, recommendations for this nutrient are based on experimentation. Half the nitrogen is applied during planting and the rest, 40–60 days later. As positive responses to nitrogen have not been observed, some farmers do not use it. When it is used, it is applied as ammonium sulfate or urea.

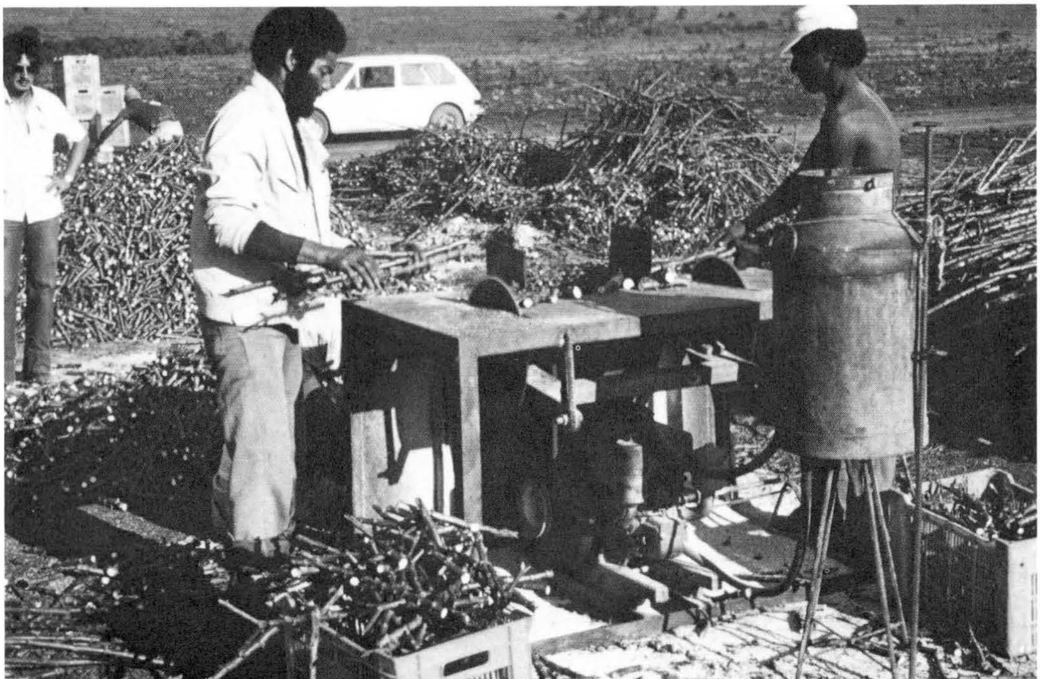

Fig. 2. Stake preparation, Minas Gerais, Brazil.

Fig. 3. The Sans planter.

In some areas, lime spreaders are used for nitrogen application, but we recommend against this procedure, especially for the second application, because it may cause foliar damage and is less effective than application during planting.

Plants in soils with less than 1 ppm Zn show positive responses to Zn applications of 10–20 kg/ha (45–90 kg of zinc sulfate). There are some commercial fertilizers that include zinc, which makes its application easier. When dolomitic limestone is not applied, magnesium sulfate is recommended, although it is not widely applied.

Planting Equipment

The Sans planter plants two rows at a time and requires two men to feed the roller. It is most commonly operated at 2 km/h. A third man follows the planter to cover stakes that have not been well covered with soil and to correct any mistakes. The machine must be regulated in such a way that depth and spacing are as recommended by the manufacturer. One 60-hp tractor plants 2.5–3.0 ha in 10 h (Fig. 3).

The Martins planter, manufactured at Campos, Rio de Janeiro, is a modified sugarcane planter, developed as a result of demands from farmers after the formation of PROALCOOL (Fig. 4). This planter opens furrows, applies fertilizer, cuts and treats stakes, plants and covers the stakes, and compacts the soil. It can plant 5 ha/day. The operation of this equipment requires two men at the cutting section and two more at the feeding section. The stakes are sprayed with a solution of Dithane M-45 or Manzate (100 g/100 l H_2O) at the same time as they are being cut.

Spacing

Spacing depends on soil fertility, plant architecture, cultivation system, future use, and climate. According to Normanha and Pereira (1950), Nunes and Oliveira (1972), Mattos et al. (1973), Siqueira (1973), Correa (1971), Silva (1971), and Sampaio and Conceição (1972), best spacings are 0.60–1.40 m between rows and 0.40–1.00 m between plants. Between 1.00 × 0.60 and 1.00 × 0.50 m is generally recommended. In cerrado soils, 1.00 × 0.50 m (20 000 plants/ha) has been adopted. With this spacing, although losses of up to 20% still occur, the planting density is within the range considered ideal for this type of soil. However, in cerrado soils Correa (1971) showed that higher yields were obtained in closer spacings (Table 2). These conditions at the same time reduced quality, diameter, and size of roots.

Cassava Pruning

Cassava pruning is a cultural practice adopted in some regions, especially South Brazil, mainly as protection against frost. The effects have been more noxious than beneficial because pruning helps disease spread; diminishes root production and carbohydrate levels; increases branch numbers and, hence, competition; and increases fibre levels in the roots. Besides protection against frost, its positive effects include insect control (stemborer) and increased branches for use as forage. Also, emerging stems tend to grow faster and more erect than the old ones and, thus, are at times better as planting material. Although a source of good planting material, pruning increases production costs and reduces yields. A better method of obtaining planting material is to select stakes during root harvest.

Table 2. Mean root and stem production (t/ha) with different populations of cassava cultivar Riqueza (Correa 1971).

Spacing (m)	Population/ha	Roots (t/ha)	Stem (t/ha)
1.00 × 0.30	33 330	26.1	31.1
1.00 × 0.60	16 660	24.1	27.2
1.00 × 0.90	11 110	15.5	17.3
1.00 × 1.20	8 330	13.3	13.5

Weed Control

When cassava is planted in newly cleared areas, weed control is restricted to the elimination of emerging sprouts. Herbicide applications are not necessary, as manual or mechanical control is satisfactory. With time, fields become infested with *Melinis minutiflora*, *Cenchrus echinata*, *Brachiaria plantaginea*, *Cynodon dactilon*, *Digitaria sanguinalis*, *Panicum* sp., and *Portulaca oleracea*. Different experiments have been carried out in the region to determine the most appropriate herbicides and their application rates. Diuron and Alachlor or a mixture of both

Fig. 4. The Martins planter.

have given the best results at preemergence. Other products are being tested.

Although specific herbicide recommendations exist, they are not being followed. In demonstration areas, herbicides have provided good weed control up to 70 days. One reason for not utilizing herbicides more extensively is that mechanical weeding is usually done 40–50 days after planting.

Another aspect to be considered is that cassava does not grow fast enough to shade the soil and, thus, to complement the weed-killing action of the herbicide. Mechanical weeding is generally done when the plants are 20 cm tall and the number of times depends on weed infestation.

The cultivator normally used weeds 3 rows at a time, penetrating 10 cm deep between rows and moving soil toward the cassava to eliminate emerging weeds. One 85-h.p. tractor pulling a 3-hoe cultivator is able to clean 1 ha in 40 minutes. When additional weeding is necessary, it takes 5 men/day. Weeding is more effective on sunny days. With added equipment on the cultivator, it is possible to apply fertilizers at the same time.

During the second vegetative cycle the weed problem is worse than during the first cycle. The weeds grow before cassava recovers to shade the soil. At this stage hand weeding is the only possibility. Weeds compete with plants for nutrients, water, and light, reducing productivity and making cassava harvesting very difficult and expensive. Hand harvesting at this stage demands at least 10 men/ha/day.

Insect Control

Large-scale cassava production leads to ecosystem imbalances and heavy insect infestations, especially of cassava hornworm (*Erinnyis ello* and *E. alope*), the most important pest. Besides the direct damage it causes, the hornworm is one of the principal agents of bacteriosis dissemination.

Chemical control has been done with Sevin powder (Carbaryl), Thuricide (*Bacillus thuringiensis*), and finally with Methil Parathion 1% + Endrin 1.5% (7 kg/ha). Methil Parathion + Endrin (powder) were applied using a duster covering from 50 to 100 ha/day. At present, hornworm is controlled biologically. Those responsible for phytosanitary control keep records of pest levels and introduce control measures only when absolutely necessary. Moderate use of insecticides has been recommended.

The white ant (*Syntermes* sp.), which attacks the cassava planting material, is not currently prevalent enough to warrant control measures, which would contaminate the soil with chlorinated insecticides. Recently, small aircraft have been used for pesticide applications, but arthropods, the natural enemies of the cassava hornworm, have been killed as well.

Measures to control ants (*Atta* sp. and *Acromyrmex* sp.) are undertaken at two stages: first, during soil preparations and, second, during the cassava growth cycle. Initial control is before woody areas are cleared (felling), again 40 days after, and once more during the last disking. During the cassava growth cycle, any new nests should be eliminated; gases, dusts, and baits are normally used.

Control measures are occasionally needed against thrips, mites, and lace bedbugs. The lace bedbug (*Vatiga illudens*) causes the most severe damage and so far the control systems have been unsuccessful.

Diseases

Most of the cultivars introduced into the Cerrado were infected with bacteriosis (*Xanthomonas manihotis*), the most serious disease in the region. It limits production and has even been known to cause 100% losses. It is more prevalent during the rainy season when relative humidity is higher and thermal variations greater. Some cultivars, such as Sonora, Caapora, Mico, IAC 12-829, Iracema (IAC 7-127), Mantiqueira, Engana Ladrao, are considered to be resistant to bacteriosis; they have been introduced and are under observation.

Some farmers carry out roguing to eliminate plants infected with bacteriosis.

Among fungal diseases the most common are caused by *Cercospora* and *Oidium*, but there are no quantitative evaluations of the damage caused.

Stake Treatment

The following products have been recommended for stake treatment: Dithane M-45, 2 g/l; Vitigram, 2 g/l; and zinc sulfate, 20 g/l. The solution is compatible but tends to deteriorate with time. In a study of treatments, stakes were immersed in the solution for 15 minutes as protection against zinc deficiencies and pathogenic attacks. This operation added one more step to the production process; treatment was done in a 1000-l water container by immersion of small boxes containing the stakes. The treatment system varies according to production scale, with the most efficient including four 1000-l treatment containers plus a solution container placed above the others so that the solution flows by gravity. After stake treatment, the solution is pumped into another container for reuse.

At the end of a working day, the solution is completely dirty, and the impurities reduce treatment efficiency and bactericide action. Therefore, the solution is changed every day. The principle of this method is used in the Martins planter where the stakes are cut and sprayed simultaneously with Dithane M-45 or Manzate (100 g/l).

Harvesting

With the initiation of the Programa Nacional do Alcool and the possibilities of root utilization year round, harvesting criteria have changed. Harvesting in a large plantation is a complicated task that demands careful programing to satisfy both the farmer and the consumer.

Harvest Planning

When harvesting takes place on more than 300 days a year, some criteria are taken into account to improve its execution: harvest according to cultivar and characteristics (early, medium, or late); sample sections to be harvested to determine different harvesting options; harvest plots earlier where climatic conditions make the task difficult during rainy periods; harvest those plots with low stand and infested with weeds; immediately harvest those plots with phytosanitary problems and eliminate all vegetative material; conserve the best plots for planting material according to needs; if possible, harvest at the same time as planting to avoid stake storage; utilize aerial part as forage or for other purposes; and harvest according to economic factors.

Hand Harvesting

Hand harvesting is very common in large plantations; it involves two stages: pruning the aerial part of the plant and harvesting the roots with the help of mechanical tools.

Branch pruning is the first step, although it is not always done for erect cultivars. It involves removal of the aerial part of the plant — an operation that facilitates root harvest; a machete or other cutting device is usually used. Pruning is done 30–50 cm above the soil surface, and a crew of 7–8 can prune approximately 15 000 plants a day.

Roots are harvested by hand oscillation, sometimes with the help of a hoe. The handle serves as a lever when the tool is in the soil under the stump. Roots remaining in the soil are extracted with the help of a mattock (hoe) and piled nearby along with the stumps.

The detachment of the roots from the stump is done by hand or with a machete. The stumps are piled and are later burned or removed. The roots from 4–5 rows are collected in piles every 20 m along one row. Then, they are packed in plastic boxes or placed in trailers to be taken to the main transportation system.

Harvesting Efficiency

Harvesting efficiency depends on many factors. One man may harvest 800–1000 kg/day but if working conditions are not optimal, the amount may be 500 kg/day.

Plastic boxes with a capacity of 25 kg have been used for packing the roots. Packing and loading a yield of 16 t/ha requires 16–20 men/day, which increases production cost.

Trailers carry the roots from the field to the final transportation system. Roots must be taken to a factory in less than 48 h because of root rot risks from handling.

Semimechanized Harvesting

Branches are either cut by hand or by machine. Some cutters convert the aerial part into forage or silage and deposit the material in trailers for transport to the silos. One factory produced 400 t of silage uing 2/3 of the aerial part of the plants. The quality of the product was very good and cattle were fed up to 32 kg of silage a day without any problems.

Mechanical Harvesting

Harvesters attached to the hydraulic system of a tractor are still under development and have not given satisfactory yields. The ones used at Felixlândia were responsible for root losses up to 40%. The most promising harvesters, developed by Ceará Maquina Agricolas (CEMAG) with INT support, are being tested in farm trials.

In an effort to overcome the problems in harvesting, one farmer from Cordisburgo imported a cassava harvester from Agri-Project International and is testing it. Results so far indicate that the machine is a very efficient cassava harvester. Meanwhile, mechanical harvesting is still under development.

Crop Rotation

Crop rotation is commonly recommended for all crops in every type of soil and is being adopted in large-scale commercial plantations. It avoids imbalances in soil nutrients; controls some pests and diseases, and allows the utilization of residues left by other crops as manure. Soybeans are widely used in crop rotation systems.

Principal Problems

Although some cassava technology exists, changing from a typically subsistence crop to more extensive production has produced problems in Curvelo; the most important are that: (1) in new areas, the farmers' lack of experience may bring negative consequences to cassava production; (2) the lack of selected planting material in the region may affect the agroindustrial operation; (3) inadequate mechanization in areas of agricultural frontier expansion may affect the planting schemes, reducing productivity; (4) high input costs, especially of fertilizers and correctives, may lead farmers to use them improperly; and (5) climatic conditions and the presence of insects and diseases caused by changes in the ecological balance in the region may affect the crop.

The Effect of Mycorrhizal Inoculation on the Phosphorus Nutrition of Cassava

Reinhardt H. Howeler[1]

The effect of mycorrhizal inoculation of cassava on plant growth and P uptake was studied in sterilized and unsterilized soil, to which eight levels of P had been applied, as well as in flowing nutrient solution at four different P concentrations. Inoculation had the greatest beneficial effect on cassava grown in sterilized soil to which 2 t P/ha was applied, increasing dry matter production nearly threefold and total P uptake about sevenfold. In the unsterilized soil both dry matter production and P uptake increased about 50% when 0.5 t P/ha was applied. In the soil experiment cassava became mycorrhizal only at the intermediate P application rates of 0.1 to 4 t/ha, corresponding to soil solution P concentrations of about 2 to 52 μM. Without applied P and at the two highest rates of applied P (8 and 16 t/ha) mycorrhizal inoculation had no beneficial effect and the percent infection was low, especially in the unsterilized soil.

In flowing solution culture, inoculation significantly increased DM production of eight cassava cultivars at the intermediate P concentration of 1 μM, whereas it had no effect on maize, rice, cowpea, and *Phaseolus* beans. The latter species produced maximum yields at 1 μM P, but cassava required at least 10 μM P. At 10 and 100 μM P cassava roots did not become mycorrhizal after inoculation, whereas at the lowest concentration of 0.1 μM P the roots became mycorrhizal, but this had no significant effect on yield. Some implications of cassava's apparent dependence on mycorrhiza are discussed.

It is well known that cassava has the ability to grow on very acid and infertile soils (Cock and Howeler 1978) and often does not respond to fertilization even in soils with rather low levels of available plant nutrients. Cassava is also considered a scavenger plant to be grown as the last crop in a rotation before returning the nutrient depleted plot back into bush fallow in the slash-and-burn agriculture system still practiced in much of the humid tropics (Ofori 1973). Because cassava apparently can extract nutrients from very infertile soils it has logically been concluded that it must have a very efficient root system.

However, recent research with cassava in flowing solution cultures at the University of Queensland indicated that cassava had a higher external P requirement than almost any other crop studied (Jintakanon et al. 1979), and actually had a very low rate of uptake of P as well as of K and N compared with other crops (Edwards et al. 1977). Although cassava may have a mechanism to adapt to low fertility conditions, e.g. through a reduced growth rate, a high efficiency in nutrient utilization in dry matter production, a low nutrient gradient within the plant, and a large root-to-top ratio (Edwards et al. 1977; Spear et al. 1978), it does not appear to be an especially efficient absorber of nutrients, at least under nutrient solution conditions. Microscopic observation also indicates that cassava has a coarse root system, with relatively thick and poorly branched roots. Root hairs may be present, but are not abundant and in nutrient solution conditions are essentially absent. From these apparently contradictory observations it was postulated (Howeler 1977) that an efficient mycorrhizal association under natural soil conditions might explain these anomalies.

Mycorrhiza, or more precisely, the vesicular-arbuscular endotrophic mycorrhiza (VAM), are fungi that live in symbiosis with plant roots. They form vesicles and arbuscules in the cells of the root cortex (Hepper and Mosse 1975), from which hyphae grow through the intercellular

[1]Soil Scientist, Cassava Program, CIAT, Cali, Colombia.

spaces to the outside of the root and into the surrounding soil. The fungus utilizes carbohydrates excreted from the roots, and in turn absorbs nutrients from the soil solution and releases these to the plant. It is believed that the main beneficial effect of mycorrhiza is that of exploring more intensively a certain soil volume. This is of special importance for plants having a coarse root system, and particularly for the uptake of P. This element reaches plant roots mainly by the slow process of diffusion (Barber et al. 1963), and is therefore absorbed only from a rather narrow zone around each root. The hyphal extensions of the fungus can explore the soil beyond this narrow depletion zone.

The beneficial effects of mycorrhiza on some forest species has been known for years and pine trees are routinely inoculated before planting (Redhead 1979).

However, it is only in the last 10 years that the beneficial effect of mycorrhiza on field crops has been recognized. Research on mycorrhizal association in cassava was first reported by IITA (1976), where it was shown that cassava, like many other field crops, do indeed become infected with mycorrhiza under natural field conditions. Potty (1978) also reported mycorrhizal infections in cassava as well as in sweet potato and *Coleus*. More recently, Yost and Fox (1979) and Zaag et al. (1979) in Hawaii found that soil sterilization with methyl bromide severely reduced plant growth and P uptake in plots, not having received or having received only small applications of P, while it had little effect at high rates of applied P. Cassava and *Stylosanthes hamata* were two of the seven species studied that were most affected by the elimination of the indigenous mycorrhiza from the soil through sterilization. Thus, from this work it appeared that cassava is highly dependent on a mycorrhizal association for P uptake from low-P soils. The objective of the work reported here was to try to inoculate cassava artifically with mycorrhiza and to determine the effect on the growth and nutrient uptake in soil with different levels of applied P as well as in nutrient solutions of different P concentrations.

Mycorrhizal Effect in Soil

Eight P levels were established in a very P deficient and highly P-fixing oxisol in pots by addition of $CaH_2PO_4 \cdot H_2O$ corresponding to 0, 0.1, 0.5, 1, 2, 4, 8, and 16 t/ha of P. The highest rate corresponds with about 35 t P_2O_5/ha. A basal application of fairly high doses of N, K, Mg, and Zn was also applied to prevent the induction of other nutritional deficiencies. After 7 weeks of incubation, half of the pots were sterilized with methyl bromide to eliminate the indigenous mycorrhiza. Cassava tip cuttings of cv. M Aus 10 were rooted in small peat pots with coarse sand in two misting chambers. When the roots were just emerging from the callus, the plantlets in one chamber were inoculated with mycorrhiza by placing 2–3 g of fresh mycorrhiza-infected cassava roots under each cutting. Plants in the other misting chamber received the same amount of dead inoculum (autoclaved mycorrhizal roots) for the noninoculated treatments. When the cassava roots had grown through the walls of the peat pots, the plants were transferred to pots with sterilized and unsterilized soil. Thus, 32 treatments were established: 8 P levels in sterilized and unsterilized soil and planted with inoculated and noninoculated plants. They were grown for two months in the greenhouse. After about 1 month the P concentration in the soil solution of each P treatment in both sterilized and unsterilized soil was determined by analysis of the soil solution extracted by centrifugation according to the method of Gillman (1976).

Figure 1 shows that the P concentration in soil solution increased from less than 1 to approximately 700 μM (0.031–22 ppm) due to P treatments and that sterilization had no effect or slightly increased the P concentration in solution.

After about 2 weeks, plants started to show a response to applied P. In the sterilized soil at low P levels, plants showed typical symptoms of extreme P deficiency and started to lag behind those in the unsterilized soil. At 4–5 weeks a positive response to inoculation was observed, and at 6 weeks this response was very marked and consistent at intermediate P levels, especially in the sterilized soil. At harvest the youngest fully expanded leaves (YFEL) were separated from the rest of the tops, and roots were carefully washed out from the soil and separated into fibrous and tuberous roots. These samples were dried, weighed, and analyzed for P, K, Ca, Mg, and Zn. Also, just before harvest three soil cores were taken in each pot, the fibrous roots were carefully washed out and stored in alcohol for subsequent staining with trypan blue and observation of mycorrhizal infection by the method of Phillips and Hayman (1970).

Figure 2 shows the effect of P application, sterilization, and inoculation on dry matter production. Maximum dry-matter production was

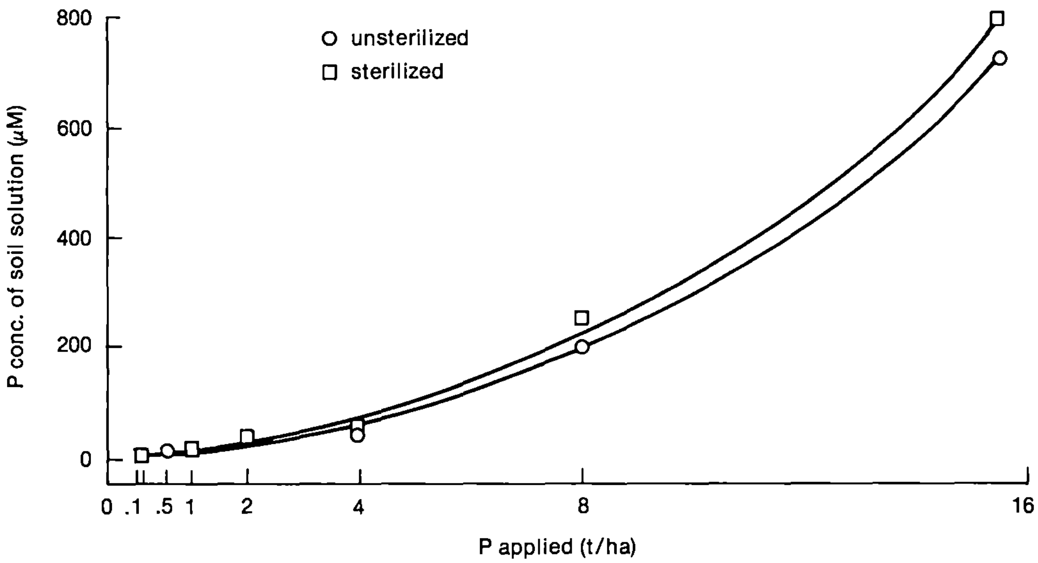

Fig. 1. Effect of P application rates and methyl bromide sterilization on soil solution P concentrations at field capacity in an oxisol (Maleny Krasnozem).

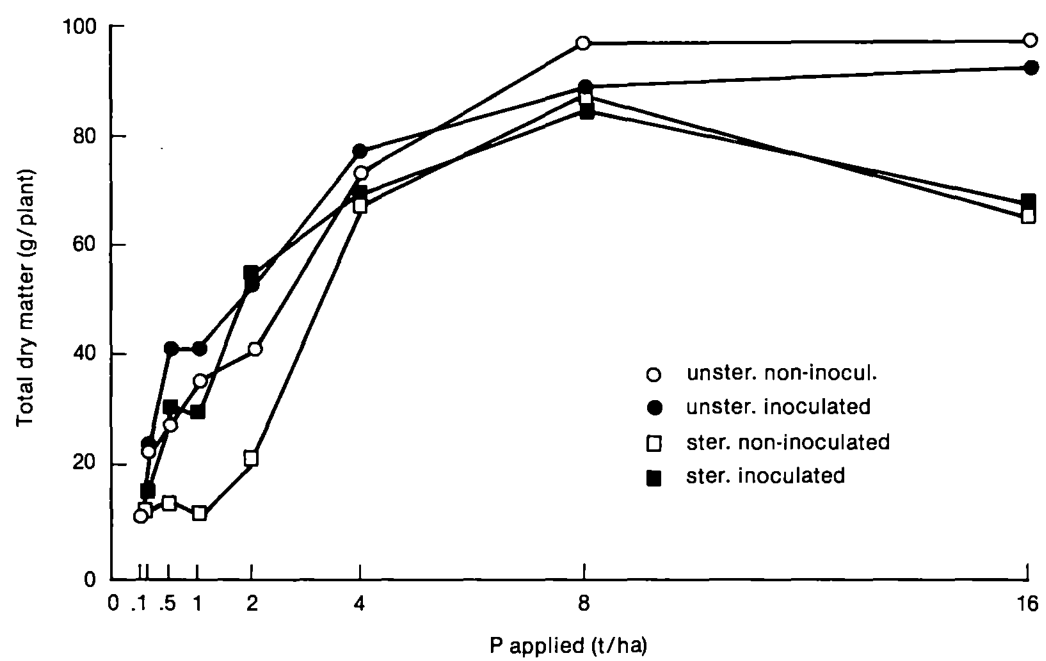

Fig. 2. Effect of soil sterilization, mycorrhizal inoculation, and P application rates on total dry matter production of cassava (cv. M Aus 10) grown for 2 months in an oxisol.

reached at 8 t P/ha irrespective of mycorrhizal treatments. In the sterilized soil higher P rates depressed yield due to salinity, which apparently resulted from a combination of extremely high P levels and a methyl-bromide induced increase in the inorganic N concentration of the soil solution (Yost and Fox 1979; Rovira 1976; Lopez and Wollum 1976).

In the unsterilized soil inoculation increased dry-matter production only at the intermediate P levels of 0.5, 1, and 2 t/ha. In the sterilized soil, however, inoculation increased plant growth up to 4 t P/ha, whereas at 2 t P/ha inoculation increased DM production as much as threefold.

The beneficial effect of inoculation was even more pronounced in terms of total P uptake by the plant (Fig. 3), which increased more than sevenfold at 2 t/ha applied P in the sterilized soil. In the unsterilized soil total P uptake increased about 50% at 0.5 t/ha applied P. Inoculation also increased the tissue concentration as well as the total uptake of Ca and Mg and increased the total uptake of K and Zn (Howeler et al. 1979). However, it is uncertain whether this is a direct effect on the uptake of these elements or whether mycorrhiza essentially increased only the P uptake, which in turn resulted in a more vigorous plant with a more extensive root system and thus a greater nutrient uptake.

Microscopic observation of the stained root samples showed that the inoculated plants were highly infected with mycorrhiza at the intermediate P levels, but with a low degree of infection at both the very high and very low rates of P application (Table 1). In the sterilized soil the noninoculated plants were essentially free of any mycorrhizal infection, as expected. However, in the unsterilized soil no infection could be observed either, which is surprising in view of the comparatively good growth and P uptake at

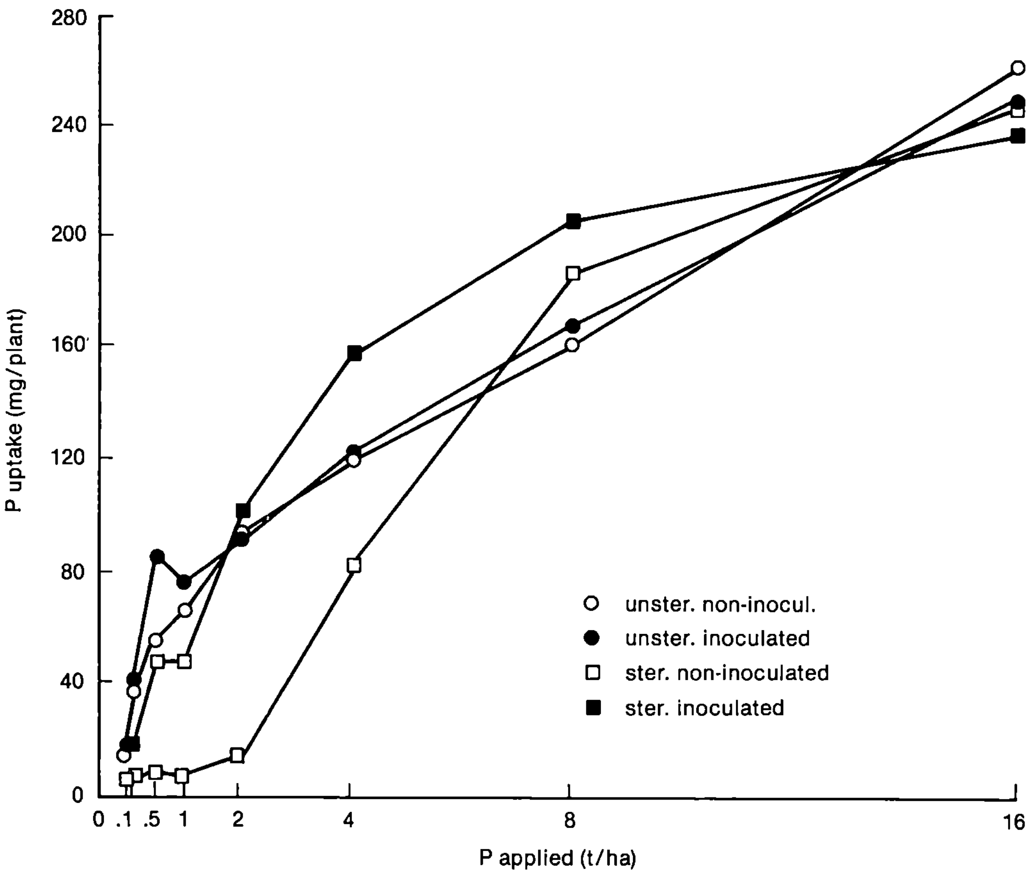

Fig. 3. Effect of soil sterilization, mycorrhizal inoculation, and P application rates on total P uptake by cassava (cv. M Aus 10) grown for 2 months in an oxisol.

Table 1. Effect of soil sterilization on percent infection of roots of cassava (cv. M Aus 10) inoculated with mycorrhiza and grown for 2 months in an oxisol at P application rates of 0–16 t/ha.

P applied (t/ha)	Unsterilized soil (% infection)	Sterilized soil (%infection)
0	0	5
0.1	14	49
0.5	38	79
1	51	65
2	53	77
4	61	45
8	9	57
16	4	14

intermediate P rates in this treatment. This might be due to the presence of some indigenous strains of mycorrhiza with extremely fine hyphae and essentially no vesicles in the roots, as has been found recently in other crops.

Many researchers (Hayman 1975; Sanders 1975; Daft and Nicolson 1969; Zaag et al. 1979; Yost and Fox 1979) have reported that the beneficial effect of mycorrhizal associations decrease as the P concentration in the soil increases, and that at extremely low P levels the association is not effective (Mosse et al. 1975; Abbott and Robson 1977). Similar results were obtained in this study, however, little is known about the range of P concentrations at which mycorrhiza are most effective. Zaag et al. (1979) reported that the beneficial effect of mycorrhiza in cassava reduced to about zero at P concentrations in soil solution above 52 μM, determined with the method of Fox and Kamprath (1970). Figure 4 shows the relation between the relative DM yield and the P concentration determined in soil solution. Inoculation with mycorrhiza was effective in increasing yields in the range from 2 to 50 μM P, which corresponds with the data from Zaag et al. (1979). It is also clear that mycorrhiza do not significantly change the plant's external P requirement, i.e., is the external P concentration corresponding to 95% of maximum yield, as the mycorrhizal effect essentially disappears at the high P concentrations necessary for near-maximum yields. The

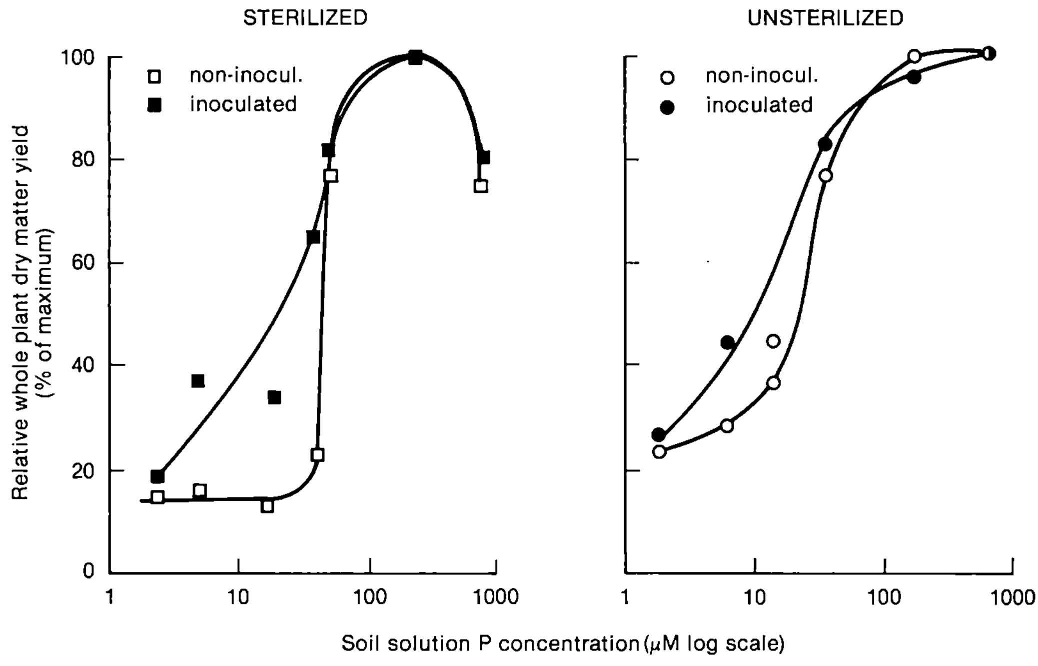

Fig. 4. The effect of soil sterilization and mycorrhizal inoculation on the relationship between relative whole plant dry matter yield and soil solution P concentration of cassava (cv. M Aus 10) grown for 2 months in an oxisol at P application rates of 0.1–16 t/ha. Soil solution P concentrations associated with 95% of maximum yield are (μM): sterilized, noninoculated 100; sterilized, inoculated 95; unsterilized, noninoculated 100; unsterilized, inoculated 130. Data for the nil P rate are not included because the soil solution P concentration was below the limit of detection.

external P requirement obtained in this trial for all mycorrhizal treatments was about 100 μM, which is not too different from the P requirement of 72 μM obtained for the same cultivar in nutrient solution by Jintakanon et al. (1979).

Mycorrhizal Effect in Flowing Nutrient Solution

If mycorrhiza play only a role in enhancing P transport to the root, their beneficial effect in a vigorously stirred nutrient solution is expected to be minimal; however, mycorrhizal infection under nutrient solution conditions has been recently reported.

In the flowing solution culture units at the University of Queensland eight cultivars of cassava and one cultivar each of maize, rice, cowpea, and *Phaseolus* bean were grown at four P concentrations of 0.1, 1, 10, and 100 μM, both in units with noninoculated plants and in units with plants inoculated with mycorrhizal infected cassava roots (Howeler et al. 1980). The P concentrations were carefully maintained at a constant level throughout the growth period by daily analysis and correction of the P concentration in each unit, as well as by continuous drip feeding of P solution at the rate of the expected P absorption by the plants. After 6 weeks, plant tops and roots were harvested, dried, weighed, and analyzed for P. Samples of roots were stained and inspected for mycorrhizal infection.

Plant growth of all cassava cultivars was vigorous at the two highest P concentrations of 10 and 100 μM irrespective of inoculation treatments. At 0.1 μM P all plants were extremely stunted with typical symptoms of P deficiency. Inoculation at this very low P concentration did not improve plant growth but did reduce the severity of deficiency symptoms. At the intermediate level of 1 μM P, plant growth was only slightly better than 0.1 μM P during the first 3 weeks. However, during the last 3 weeks the inoculated plants improved considerably showing no more deficiency symptoms, while the noninoculated plants remained extremely P deficient. In contrast, maize, rice, cowpea, and beans were stunted and P deficient only at the lowest concentration of 0.1 μM P and reached maximum growth at the next level of 1 μM P. No beneficial effect of inoculation was observed in any of these species, which all have a rather fine and extensively branched root system.

Careful observation of the root system of cassava plants revealed that those of inoculated plants at the two lowest P concentrations were covered with a slimy substance, especially near the solution surface. Microscopic examination and staining with trypan blue revealed that this substance consisted of masses of mycorrhizal hyphae covering the root surfaces and forming an intensive network of mycelium between the roots. Inside the roots these hyphae were connected to vesicles. At the two highest P concentrations and in all of the noninoculated treatments the roots were free of slime and no vesicles or hyphae were observed; roots of all other species were free of slime as well as mycorrhizal infection in all treatments. Table 2 shows the average percent root infection of the eight cassava cultivars as well as the DM production and P concentration in tops and roots as affected by the P concentration in solution and mycorrhizal inoculation. Cassava roots of inoculated plants at 0.1 μM P were clearly infected with mycorrhiza, which resulted in a significant increase in the P concentration of both tops and roots, but concentrations were still too low to cause a significant increase in plant growth and DM production. At 1 μM P, however, inoculation increased the P concentration of tops from 0.17 to 0.21% and of roots from 0.12 to 0.40% and resulted in a DM increase of about 50%. Increases in DM production due to inoculation varied among cultivars from 16 to 103%, indicating that cultivars differ significantly in their response to mycorrhizal infection. At 10 and 100 μM P cassava produced maximum yields and had a P concentration in the tops near or above the critical level of 0.4% (Howeler 1978). At these

Table 2. The effect of phosphorus concentration in solution and mycorrhizal inoculation on the average percent infection in roots, total dry matter production, and the phosphorus content of plant tops and roots of eight cassava cultivars grown in flowing solution culture.

P in solution	Root infect. (%)		Total DM (g/plant)		P in tops (%)		P in roots (%)	
(μM)	Non-inoc.	Inoc.	Non-inoc.	Inoc.	Non-inoc.	Inoc.	Non-inoc.	Inoc.
0.1	nil	30	2.24	2.15	0.071	0.087	0.094	0.139
1	nil	38	3.72	5.55	0.168	0.214	0.122	0.401
10	nil	nil	9.94	9.04	0.351	0.339	0.368	0.412
100	nil	nil	9.10	8.48	0.494	0.457	0.595	0.503

high concentrations inoculation had no beneficial effect, either in terms of tissue P concentrations or DM production. Thus, as in the soil experiment, there was no beneficial effect of mycorrhizal association at high P concentrations, and these effects would therefore be difficult to study at the relatively high P concentrations normally employed in conventional still cultures.

At the intermediate P concentration of 1 μM root growth of noninoculated cassava plants was very poor, but when inoculated it improved considerably, resulting in a great number of fine roots. Thus, it appears that without mycorrhizal infection cassava has a very coarse and inefficient root system, which explains its high P requirement in nonmycorrhizal nutrient solutions, whereas inoculation greatly improved P uptake, resulting in a more vigorous plant and a more effective root system. This would allow mycorrhizal cassava to absorb P even from very low-P soils.

Implications of Mycorrhizal Effects on Cassava Research and Production

Compared with other crops cassava appears particularly dependent on an effective mycorrhizal association. This has several important implications.

(1) Although fungicidal treatment of cassava planting material improves its storage time and sprouting, it may have a detrimental effect on mycorrhizal growth. This should be investigated.

(2) Little is known about the effect of pH, Al, Mn, and drought on mycorrhiza, and particular strains may have to be selected that tolerate adverse soil conditions of low pH, high Al and/or Mn, as well as prolonged periods of drought.

(3) Practical inoculation methods should be investigated using mycorrhizal spores or infected cassava roots as inoculum; alternatively, if mycorrhiza are not very host specific, it may be more practical to produce inoculum on grass roots etc., or grow cassava in rotation with a highly mycorrhizal pasture or food crop.

(4) Cultivar differences in P response may be due to differences in the plant's ability to absorb or utilize P efficiently, as well as its ability to form effective mycorrhizal associations. Screening methods in nutrient solution tend to overlook the latter aspect; field screenings may therefore be more meaningful, especially if cultivars are evaluated for mycorrhizal infection.

(5) Because cassava production has its greatest potential in the extensive regions of very acid and low-P soils, mycorrhizal inoculation may become of utmost practical importance to improve the plant's efficiency of phosphorus absorption.

The author gratefully acknowledges the help and suggestions of Drs D.G. Edwards and C.J. Asher of the Department of Agriculture at the University of Queensland, as well as that of Drs R.K. Jones and W. Jehne of CSIRO Cunningham Laboratory, St. Lucia, Queensland; the use of equipment and facilities during sabbatical leave of the author at the University of Queensland is greatly appreciated.

Bibliography

Abbott, L.K. and Robson, A.D. 1977. Growth stimulation of subterranean clover with vesicular arbuscular mycorrhizas. Austr. J. Agric. Res. 28, 639–649.

Acosta, J.R. and Perez, J. 1954. Abonamiento en yuca (Fertilization of cassava). Suelo Tico 7, 300–308.

Agboola, A.A. and Obigbesan, G.O. 1976. The response of some improved food crop varieties to fertilizers in the forest zone of western Nigeria. In Seminar on Fertilizer Use Development in Nigeria, Rome, Italy, 1974. Report on FAO/NORAD and Federal Department of Agriculture. Rome, Italy, Food and Agriculture Organization of the United Nations (FAO), FAO-AGL/MISC/76/3, 63–77.

Ahmad, M.J. 1973. Potential fodder and tuber yields of two varieties of tapioca. Malays. Agric. J. 49, 166–174.

Aina, P.O., Lal, R., and Taylor, G.S. 1977. Soil and crop management in relation to soil erosion in the rainforest of western Nigeria. In Soil Erosion Prediction and Control. Soil Conservation Society of America, Special Publication No. 21, 75–84.

Akobundu, I.O. 1980. Weed control in cassava cultivation in Nigeria. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA), 15p. (In press)

Albuquerque, M. 1968. Estudio de fertilidade con mandioca em latosolo amarelo esgotado da Zona do Estuario Amazonico (Fertility studies with cassava on exhausted yellow latosol in the Amazonian Estuary Zone). Belém, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Norte (IPEAN), Boletin Informativo No. 134.

1969. A mandioca na Amazonia. Belém, Pará, Brasil, Superintendencia do Desenvolvimento da Amazonia, 277p.

1970. Mandioca. Serie Fitotecnia 1(2), 1–65.

1971. Estado atual des pesquisas com mandioca no IPEAN. In Reunião da Comissão Nacional da Mandioca, 5a., Sete Lagoas, Minas Gerais. Anais. Sete Lagoas, Minas Gerais, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Centro Oeste (IPEACO), 12–17.

Albuquerque, M., Guimaraes, M.C., and Viegas, R.M.F. 1974. Epocas de plantio e de colheita em zonas mandioqueiras do Este Paraense. Belém, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Norte (IPEAN), Boletin Tecnico No. 60, 193–221.

Alvim, R., et al. 1977. A cultura da mandioca para produção de etanol. Informe Agropecuario 3(33), 3–14.

Amezquita, E. and Forsythe, W. 1975. Aplicación de la ecuación universal de pérdida de suelo en Turrialba, Costa Rica. In Congreso Latinoamericano de la ciencia del suelo 5to, Medellín, Colombia. 29p.

Amon, B.O.E. and Adentunji, S.A. 1973. The response of maize, yam and cassava to fertilizers in a rotation experiment in the savannah zone of western Nigeria. Nigerian Agric. J. 10, 91–98.

Anonymous. 1952. Le manioc (Cassava). Rech. Agron. Madagascar No. 1, 49–52.

1953. Essais de fumure du manioc (Fertilizer trials with cassava). Rech. Agron. Madagascar No. 2, 85–88.

1961. Experiments produce more cassava. Zanzibar, Department of Agriculture, Quarterly Bulletin 5–12, October-December.

Arene, O.B. and Odurukwe, S.O. 1978. The role of NPK-fertilization in inducing resistance in cassava to cassava bacterial blight. Umudike, Nigeria, National Root Crops Research Institute, 8p.

Ashokan, P.K. and Sreedharan, C. 1977. Influence of levels and time of application of potash on growth, yield and quality of tapioca (*Manihot esculenta* Crantz). J. Root Crops 3(2), 1–4.

Banco do Nordeste do Brasil. 1967. Mandioca; aspectos da cultura e indústria. Fortaleza, Ceará, Brasil.

Barber, S.A., Walker, J.M., and Vasey, E.H. 1963. Mechanisms for the movement of plant nutrients from the soil and fertilizer to the plant root. Agric. Food Chem. 11, 204–207.

Bates, W. 1957. Mechanization of tropical crops. First edition. London, Temple Press Books Ltd., 410p.

Beeny, J.M. 1970. Mechanization for tapioca. In Blencowe, E.K. and Blencowe, J.W., ed., Crop Diversification in Malaysia. Kuala Lumpur, Malaysia, Incorporated Society of Planters, 167–182.

Bellotti, A.C. 1978. An overview of cassava entomology. In Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7–12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 29–39.

Bellotti, A.C., Reyes, J.A., and Arias, B. 1980. Manejo de plagas en yuca. In Manual de Producción de Yuca. Programa de Yuca del CIAT. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 23–33.

Bellotti, A.C. and van Schoonhoven, A. 1977. World distribution, identification and control of cassava pests. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1-7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 188-193.

1978a. Mite and insect pests of cassava. Ann. Rev. Ent. 23, 39-67.

1978b. Cassava pests and their control. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series 09EC-2, 1-71.

Bertoni, M.S. 1945. Conservación de la rama de mandioca. Cartilla Agropecuária, Paraguay No. 81/83, 31-33.

Biehl, E.G. 1934. Conservação da rama da mandioca para plantio. Campo 5(4), 58-60.

Birkinshaw, F.A. 1926. A brief summary of tapioca cultivation on what is now a valuable rubber estate in province Wellesley. Malay. Agric. J. 14(11), 361-364.

Bock, K.R. and Guthrie, E.J. 1978. African mosaic disease in Kenya. In Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7-12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 41-44.

Bock, K.R., Guthrie, E.J., and Seif, A.A. 1976. Field control of cassava mosaic in Cost Province, Kenya. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1-7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 160-163.

Boerma, A.H. 1975. The world could be fed. J. Soil Water Conserv. 30, 4-11.

Bolhuis, G.G. 1939. Ongekeerd geplante stekken van cassave. Landbouw (Java), 15, 141-151.

1951. Plantmateriaal en plantmethoden van cassave. Landbouw 23(1/2/3), 97-107.

Booth, R.H. 1976. Storage of fresh cassava. I. Post-harvest deterioration and its control. Exp. Agric. 12, 103-111.

1978. A review of root rot diseases in cassava. In Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7-12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 121-133.

Botton, H. and Perraud, A. 1962. Experimentation fumure organique (gadoues-fumier) sur manioc (Effect of organic manures on cassava yield). Adiopodoumé, IDERT, 9p.

Brandao, S.S. 1959. Ensaio sobre sistemas de plantio da mandioca. Rev. Ceres 11(61), 1-7.

Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed. 1978. Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7-12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 244p.

Briceño, P.R. 1972. Investigación y desarrollo de una cosechadora de yuca. Bogotá, Colombia, Instituto Colombiano Agropecuario (ICA). Rev. ICA 7(2), 139-150.

Brieguer, F.G. and Graner, E.A. 1941. Polaridade e regeneração nas estacas de mandioca. Rev. Agric. 16, 230-246.

Calderón, H. 1972. Distancias de siembra en yuca. Manizales, Colombia, Universidad de Caldas, Facultad de Agronomía, 55p. (Agronomist Eng. thesis)

Campos, H. dos R. and Sena, Z.F. de. 1974. Profundidade do sistema radicular do aipim maragogipe (*Manihot esculenta* Crantz) em diferentes idades (Distribution of the root system of "Aipim Maragogipe" (*Manihot esculenta* Crantz) at different growing periods). Cruz das Almas, Bahía, Brasil, Universidade Federal da Bahía, Escola de Agronomia, 9p.

Carvalho, J.E.B. de. 1978. Herbicidas pré-emergentes em mandiocas recém-podados. Cruz das Almas, Bahía, Brasil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF), Comunicado Técnico No. 1, 3p.

Carvalho, J.E.B. de and Mattos, P.L.P. de. 1977/78. Seletividade de alguns herbicidas na cultura da mandioca. In Relatório Anual da CNPMF/EMBRAPA 1977/78. Cruz das Almas, Bahía, Brasil, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF), Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA).

Carvalho, J.E.B. de, Mattos, P.L.P. de, Almeida, P.A. de, and Caldas, R.C. 1977/78. Competição de herbicidas no controle das plantas daninhas na cultura da mandioca. In Relatório Anual da CNPMF/EMBRAPA 1977/78. Cruz das Almas, Bahía, Brasil, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF), Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA).

Castellar M, J.A. and Mogollón B, J.A. 1972. Estudio sobre conservación y viabilidad de semilla vegatativa de yuca. Santa Marta, Colombia, Universidad Tecnológica del Magdalena, Facultad de Agronomía, 121p. (Agronomist Eng. thesis)

Castro, A., Toro, J.C., and Celis, E. 1976. Métodos de siembra y cuidado inicial de la yuca. In Curso Sobre Producción de Yuca. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 123-128.

Castro, M.A. 1979. The new technology for cassava production. Presented at a Workshop on Pre-Release Testing of Agricultural Technology held at CIAT, Cali, Colombia, 36p.

Castro, M.A., Holguín, V.J., and Villavicencio, G.A. 1978. Efecto del ángulo de corte y posición de siembra de la estaca sobre el rendimiento de yuca. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 27p.

Celis, E. and Toro, J.C. 1974a. Seleçao e preparaçoa de material de mandioca para plántio. In Curso Especial de Aperfeiçoamento para Pesquisadores de Mandioca. Cali, Colombia, 3-31 August 1974. 80-86.

1974b. Métodos de semeadura e cuidados iniciais a tomar na cultura da mandioca. In Curso Especial de Aperfeiçoamento para Pesquisadores de Mandioca. Cali, Colombia, 3–31 August 1974. 182–186.

Central Tuber Crops Research Institute (CTCRI). 1969. Annual report. Trivandrum, India, CTCRI.

1970. Annual report. Trivandrum, India, CTCRI.

1971. Annual report. Trivandrum, India, CTCRI.

1972. Annual report. Trivandrum, India, CTCRI.

1973. Annual report. Trivandrum, India, CTCRI.

1974. Annual report. Trivandrum, India, CTCRI.

1976. Annual report. Trivandrum, India, CTCRI.

Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). 1977. Annual report 1976–1977, Turrialba, Costa Rica, CATIE, 5–30.

1978. Annual report 1977–1978. Turrialba, Costa Rica, CATIE, 36–86.

Centro Interamericano de Desarrollo Integral de Aquas y Tierras (CIDIAT). 1977. Conservacion de suelos en regiones tropicales (Africa y Madagascar). Trad. del francés por José Antonio Castillo C. Mérida, Venezuela, CIDIAT, 117p.

Centro Internacional de Agricultura Tropical (CIAT). 1971. Annual report 1970. Cali, Colombia, CIAT, 67p.

1972. Annual report 1971. Cali, Colombia, CIAT.

1973. Annual report 1972. Cali, Colombia, CIAT.

1974. Annual report 1973. Cali, Colombia, CIAT.

1975. Annual report 1974. Cali, Colombia, CIAT.

1976. Annual report 1975. Cali, Colombia, CIAT.

1977. Annual report 1976. Cali, Colombia, CIAT.

1978. Annual report 1977. Cali, Colombia, CIAT.

1979. Annual report 1978. Cali, Colombia, CIAT.

1980. Annual report 1979. Cali, Colombia, CIAT. (In press)

Chadha. T.R. 1958. Fertilizer experiments on tapioca in the Kerala State. J. Indian Soc. Soil Sci. 6, 53–63.

Chan, S.K. 1970. Notes on the growing of cassava at Serdang. In Blencowe, E.K. and Blencowe, J.W., ed., Crop Diversification in Malaysia. Kuala Lumpur, Malaysia, Incorporated Society of Planters, 139–148.

1975. In Annual Report of Field Crops Research Branch, MARDI. Selangor, Malaysia, Malaysian Agricultural Research and Development Institute (MARDI).

Cheing, B.N. 1973. Evaluation of harvesting systems of tapioca of leaf forage production. Kuala Lumpur, Malaysia, University of Malaya, Faculty of Agriculture, 88p. (B. Agr. Sci. thesis)

Chew, W.Y. 1970. Varieties and NPK fertilizers for tapioca (*Manihot utilissima* Pohl) on peat. Malays. Agric. J. 47, 483–491.

1971. The performance of tapioca, sweet potato and ginger on peat at the Federal Experiment Station, Jalan Kebun, Selangor. Kuala Lumpur, Malaysia, Agronomy Branch, Division of Agriculture, 7p.

1974. Yield of some varieties of tapioca grown on Malaysian peat as affected by different planting methods, plant densities, fertilizers and growth periods. Malays. Agric. J. 49(3), 393–402.

Chung, C.Y. 1976. Commercial tapioca production by smallholders on different soil types in the Kinta District, Perak. Kuala Lumpur, Malaysia, Extension and Advisory Services Branch, Division of Agriculture, 1–18.

Ciociola, A.I. and Marchini, L.C. 1978. Principais pragas da mandioca e seu controle. Lavras, Escola Superior de Agricultura de Lavras, 30p.

Cock, J.H. 1974. Agronomic potential for cassava production. In Araullo, E.V., Nestel, B., and Campbell, M., ed., Cassava Processing and Storage: Proceedings of an Interdisciplinary Workshop, Pattaya, Thailand, 17–19 April 1974. Ottawa, International Development Research Centre, IDRC-031e, 21–26.

1975. Fisiologia de la planta y desarrollo (Plant physiology and development). In Curso Sobre Producción de Yuca. Medellin, Instituto Colombiano Agropecuario (ICA), Regional 4.

1978. A physiological basis of yield loss in cassava due to pests. In Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7–12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 9–16.

Cock, J.H., Castro, M.A., and Toro, J.C. 1978. Agronomic implications of mechanical harvesting. In Weber, E.J., Cock, J.H., and Chouinard, A., ed., Cassava Harvesting and Processing: Proceedings of a Workshop held at CIAT, Cali, Colombia, 24–28 April 1978. Ottawa, International Development Research Centre, IDRC-114e, 60–65.

Cock, J.H. and Howeler, R.H. 1978. The ability of cassava to grow on poor soils. In Jung, G.A., ed., Crop Tolerance to Sub-Optimal Land Conditions. Madison, Wisconsin, American Society of Agronomy (ASA), Special Publication No. 32, 145–154.

Cock, J.H., MacIntyre, R., and Graham, M., ed. 1977. Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-80e, 227p.

Cock, J.H., Wholey, D., Lozano, J.C., and Toro, J.C. 1976. Sistema rápido de propagación de yuca. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series ES-20, 12p.

Coelho, J.P. and Correa, H. 1966. Uso de herbicidas em pré-emergência na cultura da mandioca. Relatório anual. Sete Lagoas, Minas Gerais, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Centro Oeste (IPEACO).

1971. Herbicidas em pré-emergência na cultura da mandioca. In Reunião da Comissão Nacional da Mandioca, 5a., Sete Lagoas, Minas Gerais. Anais. Sete Lagoas, Minas Gerais, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Centro Oeste (IPEACO), 47–50.

Coelho, J.P., Correa, H., Verdulin, H., Weikert, M.J., Robaina Echeverria, L.C., and Teixeira, N.M. 1973. Herbicidas em pré-emergência na cultura da mandioca: cálculo de deosagens de Karmex-DW e Lorox e sua análise econômica. Sete Lagoas, Minas Gerais, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Centro Oeste (IPEACO), Boletim Técnico No. 23, 5p.

Comissão de Fertilidade do Solo do Estado de Minas Gerais. 1978. Recomendacões para o uso de corretivos e fertilizantes em Minas Gerais; 3ª approximação. Belo Horizonte, Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), 79p.

Conceição, A.J. da. 1975. Instruçoes para o cultivo da mandioca. Cruz das Almas, Bahia, Brasil, Universidade Federal da Bahia, Escola de Agronomia/BRASCAN Nordeste, Serie Extensão 1(2), 22p.

1976. Da colheita da mandioca. In Primeiro Curso Intensivo Nacional de Mandioca. Cruz das Almas, Bahia, Brasil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF), 435–440.

1978. Influência de épocas de plantio na produção de raízes na cultura da mandioca (*Manihot esculenta* Crantz). Universitas, Salvador 20 especial, 5–23.

Conceição, A.J. da and Sampaio, C.V. 1973a. Competição de espaçamentos na cultura da mandioca. Cruz das Almas, Bahia, Brasil, Universidade Federal da Bahia, Escola de Agronomia/BRASCAN Nordeste, Serie Pesquisa 1(1), 80–85.

1973b. Competição de tamanhos de maniva de mandioca. In Projeto Mandioca. Cruz das Almas, Bahia, Brasil, Universidade Federal da Bahia, Escola de Agronomia/BRASCAN Nordeste, Serie Pesquisa 1, 87–89.

1975a. Influência da posição da maniva na produção da mandioca. Cruz das Almas, Bahia, Brasil, Universidade Federal da Bahia, Escola de Agronomia/BRASCAN Nordeste, Serie Pesquisa 1(1), 79–85.

1975b. Competição de cultivares industriais precoces. In Projeto Mandioca. Cruz das Almas, Bahia, Brasil, Universidade Federal da Bahia, Escola de Agronomia/BRASCAN Nordeste, Serie Pesquisa 1(1), 107–117.

1975c. Sistemas de plantio de mandioca. In Projeto Mandioca. Cruz das Almas, Bahia, Brasil, Universidade Federal da Bahia, Escola de Agronomia/ BRASCAN Nordeste, Serie Pesquisa 2(1), 119–127.

Correa, H. 1970. Mandioca do indígena à mecanização. Sete Lagoas, Minas Gerais, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Centro Oeste (IPEACO), Circular No. 10, 34p.

1971. Possibilidades de approveitamento do cerrado para cultura da mandioca. Sete Lagoas, Minas Gerais, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Centro Oeste (IPEACO), 15p.

1973. Efeito da poda na produção de ramas e raízes de mandioca. Rev. Ceres Viçosa 20(109), 148–157, Maio/Jun.

1977a. A cultura da mandioca como matéria prima na produção do álcool. In Simpósio Estadual do Álcool I. Divinópolis, Brasil, EMATER, MG, 82–99.

1977b. A mandioca na agro-indústria do álcool, curso intensivo. Lavras, Brasil, Ministério de Educação e Cultura, Escola Superior de Agricultura de Lavras. Convênio INCRA-FAEPE, 113p.

1977c. Cultura da mandioca. In Curso Intensivo Sobre a Cultura da Mandioca. Lavras, Minas Gerais, Brasil, 85p.

Correa, H., Andrade, A.M.S., Tanaka, R.T., Rocha, B.V. da, and Guedes, G.A.A. 1972. Níveis e épocas de aplicação de potássio na cultura da mandioca (*Manihot esculenta* Crantz), num latossolo vermelho escuro fase cerrado. Belo Horizonte, Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), 8p.

Correa, H., Rocha, B.V. da, Tanaka, R.T., Andrade, A.M.S., and Guedes, G.A.A. 1979. Estudo dos diferentes niveis de nitrogenio, fosforo e potassio na cultura da mandioca (*Manihot esculenta* Crantz) em latossolo vermelho escuro (Study of different levels of NPK in cassava in dark red latisols). Salvador, Bahia, Brasil, Congreso Brasileiro de Mandioca, 23–30 November.

Correa, H. and Vieira Neto, J.C. 1978. Conservação de ramas. In Curso de Capacitação de Técnicos para a Agricultura da Mandioca. Lavras, Brasil, Ministério da Educação e Cultura. ESAL. Convênio INT-FUNAT/FAEPE, 10, 23–31.

Costa, A.S. 1971. Moléstias de virus e de microplasmas da mandioca em São Paulo — Riscos na introducao de material do exterior. Agronomico (Campinas), 23, 125–128.

Cours, G. 1949. Les études scientifiques sur le manioc à la Station Agricole du Lac Alaotra. In Congrès du Manioc et de Plantes Féculentes Tropicales, Marseille. Marseille, Institut Colonial, 124–131.

1953. Le manioc (Cassava). In Recherche Agronomique de Madagascar. Inspection Générale des Services Agricoles. Compte Rendu No. 2, 78–88.

Cours, G., Fritz, J., and Ramakadimby, G. 1961. El diagnóstico felodérmico de la mandioca (Phellodermic diagnosis of the nutritional status of manioc). Fertilité 12, 3–20.

Coursey, D.G. and Haynes, P.H. 1970. Root crops and their potential as food in the tropics. World Crops, July/August, 261–265.

Crawford, J. 1961. Report on cassava cultivation in St. Elizabeth, Jamaica. Kaiser Bauxite 11p.

Cruz, P.F.N. 1977. Resultados preliminares sôbre a eficiência do *Bacillus thuringiensis* Berliner no controle do "Mandarová" da Seringueira (*Erinnyis ello* L.) (Lepidoptera: Sphingidae). Rev. Theobroma 7, 93–98.

Cunha, H.M.P. da, Conceição, J.A., and Sampaio, C.V. 1975. Observações preliminares sôbre o uso de herbicidas pré-emergentes na cultura da mandioca. Cruz das Almas, Bahia, Brasil, Convênio Universidade Federal da Bahia, Escola de Agronomia/BRASCAN Nordeste, Serie Pesquisa 2(1), 129–135.

Curiel, F.N. and Velasquez, E.J.R. 1977. Técnicas para la producción de yuca. Caracas, Venezuela, Ministerio de Agricultura y Cria, Centro Nacional de Investigaciones Agropecuarias, Región Nor-Oriental, 23p.

Curva, B.A. 1977. Respuesta de la yuca (*Manihot esculenta* Crantz) a la fertilización con NPK en Tarapoto (Response of cassava to NPK fertilization in Tarapoto). Tarapoto, Peru, Centro Regional de Investigación Agropecuaria del Oriente. Av. Investigacion 1(1). 20–25.

Daft, M.H. and Nicolson, T.H. 1969. Effect of endogone mycorrhiza on plant growth. II. Influence of soluble phosphate on endophyte and host in maize. New Phytol. 68, 945–952.

De Geus, J.G. 1967. Root crops: cassava. In De Geus, J.G., ed., Fertilizer Guide for Tropical and Subtropical Farming. Zurich, Centre d'Etude de l'Azote, 181–185.

Delgado, A. and Quevedo, H. 1977. Observaciones sobre el cultivo de la yuca en el sur del lago. Maracaibo, Venezuela, Universidad de Zulia, Facultad de Agronomía, 4p.

Department of Agriculture, Thailand. Field Crop Division, Annual reports, 1966, 1977, 1978, and 1979.

Dias, C.A. de C. 1966. Mandioca também se aduba (Cassava also has to be fertilized). Fir. 8, 14–16.

Diaz, D.A. 1978. Land preparation for cassava. In Dominquez, C., ed., Cassava Production Course. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 84–90.

Diaz, G.L. and Arismendi, L.G. 1973. Herbicidas en el cultivo de la yuca en la Sabana de Jusepín. Jusepín, Venezuela, Serie Agronomía No. 4, 11p.

Diaz, R.O., Howeler, R., and Varon, R.U. 1977. Evaluación de los analisis de suelos de las zonas productoras de yuca en Colombia (Evaluation of soil analyses in cassava-growing zones of Colombia). Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT).

Diaz, R.O. and Pinstrup-Andersen, P. 1977. Descripción agro-económica del proceso de producción de yuca en Colombia. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT).

Diaz, R.O., Pinstrup-Andersen, P., and Estrada, R.D. 1974. Costs and use of inputs in cassava production in Colombia: a brief description. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series EE-5, 40p.

Diaz, R.O., Toro, J.C., and Varon, U. 1977. Características de la producción y sistemas de seimbra. In Diaz, R.O. and Pinstrup-Andersen, P., ed., Descripción Agro-Económica del Proceso de Producción de Yuca en Colombia. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), C1–C20.

Doku, E.V. 1969. Cassava in Ghana. Accra, Ghana University Press, 32p.

Doll, J. 1977. Manejo y control de malezas en el tropico. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series GS-18.

1978. Weeds: an economic problem in cassava. In Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7–12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14. 65–69.

Doll, J.D. and Piedrahita, C.W. 1976. Methods of weed control in cassava. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series ES-21, 12p.

Doll, J.D., Pinstrup-Andersen, P., and Diaz, R.O. 1977. An agronomic survey of the weeds and weeding practices in cassava in Colombia. Weed Res. 17, 153–160.

Donkor, S.K. 1971. Investigation of suitability of the best cuttings and methods of planting cassava. Kumasi, University of Science and Technology. (B.Sc. dissertation)

Doop, J.E.A. Den 1937. Groene bemesting, kunstmest en andere factoren in sisal en cassava productie. V (Green manure, fertilizers and other factors in sisal and cassava production. V). Bergculture 9, 264–287.

Drumond, D.A., Castro, J.F., and Cruz, J.M.A. 1954. Trabalhos experimentais com a mandioca. Bol. Agric. (Belo Horizonte). 3(3/4), 67–74.

Dufournet, R. and Guarin, P. 1957. Note sur la culture du manioc à Madagascar (Note on cassava production in Madagascar). Riz Rizicul. 3, 15–38.

Dulong, R. 1971. Le manioc à Madagascar (Cassava in Madagascar). Agron. Trop. 26, 791–829.

Edwards D.G. (Undated). Nutrient requirement of Cassava. St. Lucia, Queensland, 4702, Australia, Department of Agriculture, University of Queensland, 32p. (Mimeo) (Unpublished)

Edwards, D.G. and Asher, C.J. 1979. Nutrient requirement of cassava. (Unpublished)

Edwards, D.G., Asher, C.J., and Wilson, G.L. 1977. Mineral nutrition of cassava and adaptation to low fertility conditions. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 124–130.

Edwards, D.G. and Kang, B.T. 1978. Tolerance of cassava (*Manihot esculenta* Crantz) to high soil acidity. Field Crops Res. 1, 337–346.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). 1975. Sistemas de produção para mandioca. Rio Preto, Brasil, EMBRAPA, Circular No. 48, 12p.

1976. Sistemas de produção para a mandioca. São João da Barra, Brasil, EMBRAPA, Circular No. 100, 22p.

1979. UEPAE de Manaus. Estudo da adubação. In Relatório Técnico Anual 1978. Manaus, UEPAE, 252–255.

Empresa Brasileira de Pesquisa Agropecuária (EM-

BRAPA)/Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF). 1979. Fisiologia. In Relatório Técnico Anual 1978. Cruz das Almas, Bahía, Brasil, EMBRAPA/CNPMF, 58-87.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA/EMATER). 1976. Sistemas de produção para mandioca. Estância, Brasil, EMBRAPA)/EMATER, Circular No. 125, 19p.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)/Empresa Brasileira de Transferencia de Technologia y Extensáo Rural (EMBRATER). 1976. Sistemas de produção para mandioca. Ceará, Brasil, Serie Sistemas de Produção, Boletin No. 15, 36p.

Empresa de Pesquisa Agropecuária do Estado de Minas Gerais. 1977. Sistema de produção para mandioca (Região de Cerrados). Informe Agropecuário 3(33), 14-18.

Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG). 1978. Produzir grãos: o desafio que Minas vence no cerrado. Informe Agropecuário 4(37), 3-23.

Enyi, B.A.C. 1970. The effect of age on the establishment and yield of cassava setts (*M. esculenta* Crantz). Beitr. Trop. Subtrop. Landwirt. Tropenvet. Med. 8, 71-75.

1972. The effects of spacing on growth and yield of single and multiple shoot plants of cassava. Root tuber yield and attributes. East Afr. Agric. For. J. 38(1), 23-26.

Ezeilo, W.N.O., Flinn, J.C., and Williams, L.B. 1975. Cassava producers and cassava production in the East Central State of Nigeria. Ibadan, Nigeria, National Accelerated Food Production Project, Cassava Benchmark Survev. East Central State, 27p.

Ezumah, H.C. 1979. Soil and environmental constraints for production of Cassava in West Africa. Presented at a Conference on Soil and Climatic Resources and Constraints for Food Production in West Africa. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA).

Fernandes, C.S. 1972. Clorose por deficiência mangânica em mandioca. In Anais de G[6] Reunião da Comissão Nacional da Mandioca. Recife, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Nordeste (IPEANE), 53.

Fernando, M. and Jayesundera, E.S. 1942. Cultural experiments with cassava. Trop. Agric. (Colombo), 98(3), 3-8.

Ferreira Filho, J.C., et al. 1942. Manual da mandioca, a mais brasileira das plantas úteis; cultura, e doenças, indústria. São Paulo, Brasil, Chácaras e Ouintaes 229p.

Flinn, J.C. 1975. Cassava production and consumption — a global to Nigerian overview. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA), 8p. (Mimeo)

Food and Agriculture Organization of the United Nations (FAO). 1977. Anuário de producción 1976. Rome, Italv. FAO, 116-118.

1978. Proyecciones de la FAO sobre productos básicos. Yuca: proyecciones de la oferta, la demanda y el comercio para 1985. Rome, Italy, FAO, 7p.

1979. Production yearbook 1978. Rome, Italy, FAO, 32. 116-117.

Forno, D.A. 1977. The mineral nutrition of cassava (*Manihot esculenta* Crantz) with particular reference to nitrogen. St. Lucia, Australia, University of Queensland. (Ph.D. thesis)

Fox, R.H., Talleyrand, H., and Scott, T.W. 1975. Effect of fertilization on nitrogen content of cassava. Llanera cultivar. J. Agric. Univ. P. R. 59, 115-124.

Fox, R.L. and Kamprath, E.J. 1970. Phosphate sorption isotherms for evaluating the phosphate requirements of soils. Soil Sci. Soc. Amer. Proc. 34, 902-907.

Galang, F.G. 1931. Experiments on cassava at the Lamao Experiment Station, Lamao Battan. Philipp. J. Agric. 2, 179-188.

Gallegos, P.R.R. 1976. Evaluación de producción agronómica y biomasa en sistemas de producción que incluyen yuca (*Manihot esculenta* Crantz). Turrialba, Costa Rica, Universidad de Costa Rica (UCR), Centro Agronómico Tropical de Investigación v Enseñanza (CATIE), 192p. (Thesis)

Gartner, J.J. and Perez, O. 1975. Producción de yuca. In Curso sobre la Producción de Yuca. Medellin, Colombia, Instituto Colombiano Agropecuario (ICA), Regional 4, 19-34.

Gerodetti, M. and Holle, M. 1980. Ensayo en policultivo de yuca cosechada a los doce meses: a) efectos de siembra en lomillo y plano asociada con o sin maíz y b) efecto de tres intensidades de poda a los seis meses sobre la producción de ejote (vainita) trepador en relevo. Turrialba, Costa Rica, Centro Agonómico Tropical de Investigación y Enseñanza (CATIE). (In press)

Gillman, G.P. 1976. A centrifuge method for obtaining soil solution. Australia, Division of Soils, Commonwealth Scientific and Industrial Research Organization, (CSIRO), Divisional Report No. 16, 1-6.

Godfrey-Sam-Aggrey, W. 1978. Effect of delayed hand weeding on sole crop cassava in Sierra Leone. Exp. Agric. 14, 245-252.

Godfrey-Sam-Aggrey, W. and Bundu, H.S. 1972. Growing and fertilizing cassava in three crop systems on upland soils of Sierra Leone. Sierra Leone, Njala University College, University of Sierra Leone, Circular No. 6, 19p.

Gomes, J. de C., Macedo, M.C.M., Souza, L. da S., and Caldas, R.C. 1979a. Níveis e épocas de aplicação de nitrogênio na cultura da mandioca. (*Manihot esculenta* Crantz). Cruz das Almas, Bahía, Brasil, Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF).

1979b. Níveis e épocas de aplicação de fósforio na cultura da mandioca. (*Manihot esculenta* Crantz). Cruz das Almas, Bahía, Brasil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF).

1979c. Níveis e modos de aplicação de potássio na cultura da mandioca (*Manihot esculenta* Crantz). Cruz das Almas, Bahia, Brasil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF).

Gomes, J. de C., Magalhães, A.F. de J., and Mattos, P.L.P. de 1979a. Influência da adubação mineral sobre a produçao da mandioca (*Manihot esculenta* Crantz) no estado da Bahia (The influence of mineral fertilization on cassava production in Bahia). Salvador, Bahia, Brazil, Congreso Brasileiro de Mandioca, 23-30 November.

1979b. Influência da adubação mineral da cultura da mandioca. (*Manihot esculenta* Crantz). Cruz das Almas, Bahia, Brasil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF).

Gomes, J., Souza, R.F., Rezende, J. de O., and Lemos, L.M. 1973. Efeitos de N.P.K.S. 1973. Micronutrientes e calagem na cultura da mandioca. In IPEAL. Solos. Cruz das Almas, Bahia, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Leste (IPEAL), Boletim Técnico No. 20, 51–68.

Gomez, A. 1975. Erosion y conservacion de los suelos de ladera de los departamentos de Caldas, Quindio y Risaralda (Erosion and conservation of mountain soils of the departments of Caldas, Quindio and Risaralda). In Curso de Caña en Suelos de Ladera, ICA-Manizales, 14 April 1975. Bogotá, Colombia, Instituto Colombiano Agropecuario (ICA).

Gonzales, Ch., F.J. 1973. Estudio sobre el tomaño y la posición de la estaca de yuca utilizadas en la plantación. Escuela de Ingenieria Agronómica Jusepín, Venezuela, Universidad de Oriente, 29p. (Thesis)

Gonzales, J.A. 1976. El cultivo de la yuca. Venezuela, Instituto de Investigaciones Agronómicas, Ministerio de Agricultura de Venezuela, 18p.

Grace, M.R. 1977. Cassava processing. Rome, Italy, Food and Agriculture Organization of the United Nations (FAO), 155p.

Graner, E.A. and Abrahão, J.T.M. 1970. Cultura da mandioca. Piracicaba, Brasil, Escola Superior de Agricultura "Luis de Queiroz," 24p.

Greenland, D.J. and Nye, P.H. (Undated). The soil under shifting cultivation. Harpender, England, Commonwealth Bureau of Soils, Technical Communication No. 51, 156p.

Greenstreet, N.R. and Lambourne, J. 1933. Tapioca in Malaya. Malaya Department of Agriculture, General Series 13, 32–41.

Gunatilaka, A. 1977. Effects of aluminium concentration on the growth of maize, soybean and four tropical root crops. St. Lucia, Queensland, Australia, University of Queensland. (M.Sc. thesis)

Gurnah, A.M. 1973. Effects of plant population and fertilizers on the yield and the components of yield of cassava in the forest zone of Ghana. Presented at the Third International Symposium on Tropical Root Crops held at IITA, Ibadan, Nigeria, 2–9 December 1973. Nairobi, Kenya, University of Nairobi, Department of Crop Production, 9p. (Mimeo)

1974. Effects of method of planting and the length and types of cuttings on yield and some yield components of cassava grown in the forest zone of Ghana. Ghana J. Agric. Sci. 7(2), 103–108.

Hadi, J.W. and Gozallie, D.M. 1975. Effect of spacing and NK fertilizer on the yield of Gading cassava variety. Bogor, Indonesia, Central Research Institute for Agriculture, 10p.

Hahn, S.K., Terry, E.R., Leuschner, K., Akobundu, I.O., Okali, C., and Lal, R. (Undated). Cassava improvement in Africa. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA). (Mimeo)

Harper, R.S. 1973. Cassava growing in Thailand, World Crops, March/April, 25(2), 94–97.

Hartman, H.T. and Kester, D.E. 1968. Heel versus non-heel cuttings. In Plant Propagation Principles and Practices. Second edition. Englewood Cliffs, N.J., Prentice-Hall Inc., 257–259.

Hayman, D.S. 1975. The occurrence of mycorrhiza in crops as affected by soil fertility. In Sanders, F.E., Mosse, B., and Tinker, P.B., ed., Endomycorrhizas. Proceedings of a Symposium held at the University of Leeds, 22-25 July 1974. London, Academic Press, 495–509.

Hendershott, C.H., Ayres, J.H., Brannen, S.J., Dempsey, A.H., Lehman, P.S., Obioha, F.C., Rogers, D.J., Seerley, R.W., and Tan, K.H. 1972. In A Literature Review and Research Recommendations on Cassava. Athens, Georgia, University of Georgia. 60–68.

Hendershott, C.H., et al. 1971. Um estudo da viabilidade da produção da mandioca no nordeste brasileiro. Ministério da Agricultura/Washington, D.C., United States Agency for International Development (USAID). Athens, Georgia, University of Georgia, 135p.

1972. A literature review and research recommendations on cassava (*Manihot esculenta* Crantz). Athens, Georgia, University of Georgia. 326p.

Hepper, C.M. and Mosse, B. 1975. Techniques used to study the interaction between endogone and plant roots. In Sanders, F.E., Mosse, B., and Tinker, P.B., ed., Endomycorrhizas. Proceedings of a Symposium held at the University of Leeds, 22–25 July 1974. London, Adademic Press.

Holquín, V.H., Castro, M.A., and Villavicencio, G.A. 1978. Efecto de la profundidad de siembra en el rendimiento de yuca. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 17p.

Hongsapan, S. 1962. Does planting of cassava really impoverish the soil? Kasikorn 35, 403–407.

Hossne, A.J. 1971. Study of the mechanization of cassava harvesting. Silsoe, Bedford, England, National College of Agricultural Engineering, 59p. (Thesis paper)

Howeler, R.H. 1976. La fertilization de la yuca. In Curso Sobre Producción de Yuca. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 150–162.

1977. Respuesta de la yuca a la aplicación del fósforo (The response of cassava to phosphorus). Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Seminarios Internos, Series SE-09-77.

1978. The mineral nutrition and fertilization of cassava. In Dominguez, C., ed., Cassava Production Course, Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 247–293.

1980. Review of cassava mineral nutrition and fertilization. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT).

Howeler, R.H., Cadavid, L.F., and Calvo, F.A. 1977. The interaction of lime with minor elements and phosphorus in cassava production. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 113–117.

Howeler, R.H., Edwards, D.G., and Asher, C.J. 1979. The effect of soil sterilization and mycorrhizal inoculation on the growth, nutrient uptake, and critical phosphorus concentration of cassava. Presented at the Fifth International Symposium of Tropical Root Crops held in Manila, Philippines, 17–21 September 1979.

1980. A nutrient solution technique used to study the effect of mycorrhizal association on the growth and P-uptake of cassava (*Manihot esculenta* Crantz). (Submitted for publication)

International Institute of Tropical Agriculture (IITA). 1972. Proceedings of Cassava Mosaic Workshop. Ibadan, Nigeria, IITA, 48p.

1974. Annual report. Ibadan, Nigeria, IITA.

1976. Annual report. Ibadan, Nigeria, IITA.

1977. Annual report. Ibadan, Nigeria, IITA.

International Institute of Tropical Agriculture (IITA)/Program National Manioc (PRONAM). 1977. Annual report. Ibadan, Nigeria, IITA.

1978. Annual report. Ibadan, Nigeria, IITA.

Irving, H. 1956. Fertilizer studies in eastern Nigeria 1947–51. Enugu, Nigeria, The Government Printer, Technical Bulletin No. 1, 34p.

Ives, N.C. 1951. Soil and water runoff studies in a tropical region. San José, Costa Rica, Instituto Interamericano de Ciencias Agrícolas (IICA). Turrialba 1(5), 240–244.

Jacob, A. and Uexküll, H. Von. 1973. Nutrición y abonado de los cultivos tropicales y subtropicales (Nutrition and fertilization of tropical and subtropical crops). Fourth edition, México 19, D.F., Ediciones Euroamericanas Klaus Thiele.

Jennings, D.L. 1970. Cassava in Africa. Field Crops Res. 23(3), 271–275.

1976. Cassava, *Manihot esculenta* (Euphorbiacea). In Simmonds, N.W., ed., Evolution of Crop Plants. London, Longman, 81–84.

Jeyaseelan, K.N. 1951. Studies in growth and yield of cassava. Yield in relation to size and type of set. Trop. Agric. (Colombo), 108(3), 168–171.

Jimenez, L.F. 1976. Estudio de absorción de nutrimentos en un agroecosistema de producción de frijol (*Phaseolus vulgaris* L.), maíz (*Zea mays* L.) y yuca (*Manihot esculenta* Crantz). Turrialba, Costa Rica, Universidad de Costa Rica (UCR), Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), 90p. (Thesis)

Jintakanon, S., Edwards, D.G., and Asher, C.J. 1979. An anomalous, high external phosphorus requirement for young cassava plants in solution culture. Presented at the Fifth International Symposium of Tropical Root Crops held in Manila, Philippines, 17–21 September 1979.

Juo, A.S.R. and Lal, R. 1978. Nutrient profile in a tropical alfisol and no-till system. Soil Sci. 127(3), 168–173.

Kanapathy, K. 1974. Fertilizer experiments on shallow peat under continuous cropping with tapioca. Malays. Agric. J. 49, 403–412.

Kanapathy, K. and Keat, G.A. 1970. Growing maize, sorghum and tapioca on peat soil. In Blencowe, E.K. and Blencowe, J.W., ed., Crop Diversification in Malaysia. Kuala Lumpur, Malaysia, Incorporated Society of Planters, 25–35.

Kartha, K.K. and Gamborg, O.L. 1979. Meristem culture techniques in the production of disease-free plants and freeze-preservation of germ plasm of tropical tuber crops and grain legumes. In Maraite, H. and Meyer, J.A., ed., Proceedings of the International Symposium of Diseases of Tropical Food Crops, Louvain-la-Neuve, Belgium, 1978. Louvain-la-Neuve, Université Catholique de Louvain, 267–283.

Kass, D.C. 1976. Simultaneous polyculture of tropical crops with special reference to the management of sandy soils of the Brazilian Amazon. Ithaca, New York, Cornell University, 265p. (Ph.D. thesis)

Kawano, D., Amaya, A., Daza, P., and Ríos, M. 1978. Factors affecting efficiency of hybridization and selection in cassava. Crop. Sci. 18, 373–376.

Keating, B.A., Evenson, J.P., and Edwards, D.G. 1979. Effect of preharvest fertilization of cassava (*Manihot esculenta* Crantz) prior to cutting for planting material, on subsequent establishment and root yield. Presented at the Fifth International Symposium of Tropical Root Crops held in Manila, Philippines, 17–21 September 1979.

Kemp, D.C. 1978. Harvesting: a field demonstration and evaluation of two machines. In Weber, E.J., Cock, J.H., and Chouinard, A., ed., Cassava Harvesting and Processing: Proceedings of a Workshop held at CIAT, Cali, Colombia, 24–28 April 1978. Ottawa, International Development Research Centre, IDRC-114e, 53–57.

Kiernowski, S. 1950. Conservación de los tallos de mandioca. Chacra 20(233), 60–61.

Koch, L. 1916. Het plantn van cassave volgens de methode van Heemstede Obelt vergeleken met de gewone bij de bevolking in swang zijnde methoden. Teysmannia 27, 240–245.

Krantz, B.A., et al. 1974. Cropping patterns for increasing and stabilizing agricultural production in the semi-arid tropics. In International Workshops on Farming Systems, Hyderabad, India, 1974. Hyderabad, India, International Crops Research

Institute for the Semi-Arid Tropics (ICRISAT), 217–248.

Krochmal, A. 1969. Propagation of cassava. World Crops 21(3), 193–195.

Krochmal, A. and Samuels, G. 1970. The influence of NPK levels on the growth and tuber development of cassava in tanks. Ceiba 16(2), 35–43.

Kumar, C.R. Mohan, Mandal, R.C., and Magoon, M.L. 1971. Influence of potash on cassava. Indian J. Agron. 16, 82–84.

Kumar, C.R. Mohan, Mandal, R.C., Nair, G.M., and Hrishi, N. 1977. Effect of farm yard manure and NPK on cassava. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 122–124.

Kunju, U.M. 1972. Tapioca a food cum industrial crop. Farmer Parliament 7(10), 9–10, 29.

Lal, R. 1975. Role of mulching techniques in tropical soil and water management. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA), Technical Bulletin No. 1.

1976. Soil erosion problems on an alfisol in western Nigeria and their control. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA), Monograph No. 1, 104p.

1977. Soil-conserving versus soil-degrading crops and soil management for erosion control. In Greenland, D.J. and Lal, R., ed., Soil Conservation and Management in the Humid Tropics. New York, John Wiley and Sons Inc., 81–86.

1979. Conservation — effective farming systems for the humid tropics. Proceedings of the American Society of Agronomy (ASA) Symposium "Soil Erosion and Conservation in The Tropics" 5–10 August 1979. Colorado, Fort Collins, USA.

Lal, R., Wilson, G.F., and Okigbo, B.N. 1977. No-till farming after various grasses and leguminous cover crops in tropical alfisol. 1. Crop performance. Field Crops Res. 1, 71–84.

1979. Changes in properties of an alfisol produced by various crop covers. Soil Sci. 126(6), 377–382.

Lambourne, J. 1927. A preliminary report on tapioca as a catch-crop with oil palms. Malay. Agric. J. 15, 104–113.

Leihner, D.E. 1978. Follow-up evaluation of two harvesting machines. In Weber, E.J., Cock, J.H., and Chouinard, A., ed., Cassava Harvesting and Processing: Proceedings of a Workshop held at CIAT, Cali, Colombia, 24–28 April 1978. Ottawa, International Development Research Centre, IDRC-114e, 58–59.

1979. New technology for cassava intercropping. Presented at a Workshop on Pre-Release Testing of Agricultural Technology held at CIAT, Cali, Colombia, 28p.

Lopez, A.S. and Guedes, G.A.A. 1978. Considerações sobre calagem e adubação química para a cultura da mandioca. In Curso de Capacitacão de Técnicos para a Cultura da Mandioca. Lavras, Ministério da Educação, Escola Superior de Agricultura de Lavras, 33p.

Lopez, A.S. and Wollum, A.G. 1976. Comparative effects of methylbromide, propylene oxide, and autoclave sterilization on specific soil chemical characteristics. Turrialba 26, 351–355.

Loria, W. 1962. Influencia del tamaño y posición de la estaca de yuca en el arraigamiento, rendimiento y producción de follaje. American Society of Agricultural Science, Caribbean Region Proceedings, 6, 20–23.

Lozano, J.C. 1977. Cassava (*Manihot esculenta* Crantz) In Hewitt, B.W. and Chiarappa, L., ed., Plant Health and Quarantine in International Transfer of Genetic Resources. Cleveland, Ohio, CRC Press Inc., 346p.

1978a. An overview of cassava pathology. In Maraite, H. and Meyer, J.A., ed., Proceedings of an International Symposium on Diseases of Tropical Food Crops, Louvain-la-Neuve, Belgium, 1978. Louvain-La-Neuve, Université Catholique de Louvain, 13–58.

1978b. General considerations of cassava pathology. In Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7–12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 17–27.

Lozano, J.C. and Booth, R.H. 1974. Diseases of cassava (*Manihot esculenta* Crantz). PANS (Pest Artic. News Summ.), 20(1), 30–54.

Lozano, J.C., Byrne, D., and Bellotti, A. 1980. Cassava/ecosystem relationships and their influence on breeding strategy. PANS (Pest Artic. News Summ.), 26. (In press)

Lozano, J.C., Cock, J.H., and Castaño, J. 1978. New developments in cassava storage. In Brekelbaum, T. Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7–12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 135–142.

Lozano, J.C., et al. 1976. Problemas no cultivo da mandioca. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 127p.

Lozano, J.C. and Terry, E.R. 1977. Cassava diseases and their control. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 156–160.

1978. Cassava diseases and their control. In Dominguez, C., ed., Cassava Production Course. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 195-203.

Lozano, J.C., Toro, J.C., Castro, A., and Bellotti, A. 1977. Production of cassava planting material. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series GE-17, 28p.

1978. Problemas relacionados con la "semilla" de la yuca (*Manihot esculenta* Crantz). In Curso

Sobre Producción de Yuca. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 78–79.

Lulofs, R.B. 1970. A study of method and costs for commercial planting of tapioca in Kedah, Malaysia. In Blencowe, E.K. and Blencowe, J.W., ed., Crop Diversification in Malaysia, Kuala Lumpur, Malaysia, Incorporated Society of Planters, 149–166.

Makanjuola, G.A. 1975. The semi-automatic device for planting cassava stem cuttings on ridges. Appro. Tech. 2(4), 24–25.

Malavolta, E.C., J.A. de, Coury, T., Graner, E.A., Pacheco, J.A. de C., and Brasil Sobrinho, M.O.C. do. 1953. Adubação da mandioca (*Manihot utilissima* Pohl). Anais da Escola Superior de Agricultura Luiz de Queiroz. Piracicaba 10, 217–222.

Malavolta, E.C., J.A. de., Pacheco, J.A. de C., Graner, E.A., Coury, T., and Brasil Sobrinho, M.O.C. do. 1954. Estudos sôbre a alimentação mineral da mandioca (*Manihot utilissima* Pohl). Anais da Escola Superior de Agricultura Luiz de Queiroz. Piracicaba 11, 21–40.

Mandal, R.C., Singh, K.D., and Magoon, M.L. 1971. Relative efficacy of different sources, levels and split application of nitrogen in tapioca. Indian J. Agron. 16, 449–452.

Mandal, R.C., Singh, K.D., and Maini, S.B. 1973. Effect of plant density, fertility level and shoot number on tuber yield and quality of tapioca hybrids. Indian J. Agron. 18(4), 498–503.

Mannering, J.V., Meyer, L.D., and Johnson, C.B. 1968. Infiltration and erosion as affected by minimum tillage for corn *Zea mays* (L.). Soil Sci. Soc. Am. Proc. 30(1), 101–105.

Maraite, H. and Meyer, J.A., ed. 1979. Proceedings of the international symposium of diseases of tropical food crops, Louvain-la-Neuve, Belgium, 1978. Louvain-la-Neuve, Université Catholique de Louvain.

Mattos, P.L.P. de. 1978. Fileira dupla; uma prática viável para o cultivo da mandioca. Mandi-Noticias, Brasília, 1(4), 3–4.

1979. Plantio de mandioca em fileira dupla. Cruz das Almas, Bahía, Brasil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF), Comunicado Técnico 3, 5p.

Mattos, P.L.P. de, Gomes, J. de C., and Matos, A.O. de. 1973. Cultura da mandioca. Cruz das Almas, Bahía, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Leste (IPEAL), Circular No. 27, 13p.

Maynard, D.M. 1979. Nutritional disorders of vegetable crops: a review. J. Plant Nutr. 1, 1–23.

Mejia-Franco, R. 1946. El cultivo de la yuca y su explotación industrial; parte 3; cuidados del cultivo; fertilización del suelo; enfermedades fungosas, y su tratamiento; plagas y su represión; cosecha (The cultivation of cassava and its industrial exploitation part 3; cultural practices; soil fertilization; fungus diseases and their treatment; pests and their repression; harvesting). Agric. Trop. 2(3), 13–21.

Mendes, C.T. 1940. Contribuiçoẽs para o estudo da mandioca. São Paulo, Secretaria da Agricultura Indústria e Comércio (SAIC), 99p.

1949. Conservaçao da rama da mandioca. Granja (Brasil), 5(47–48), 50.

Menezes, D.M. de. 1958. Rendimento da mandioca e do feijao em função da época de plantio. Rio de Janeiro, Brasil, Centro Nacional de Ensino e Pesquisa Agronomicas, Comunicado Técnico No. 5, 18p.

Montaldo, A. 1966. El cultivo de la yuca. Maracay, Universidad Central de Venezuela, Instituto de Agronomía, Publicación Divulgativa No. 4, 8p.

Monteiro, F.P. 1963. Valor economico da mandioca e trabalho mecanizado no cultivo. Rural (Brasil), 511(43), 16.

Moody, K. 1972. Weed control in cassava. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA), 5p.

Moody, K. and Ezumah, H.C. 1974. Weed control in major tropical root and tuber crops — review. PANS (Pest Artic. News Summ.), 24(3), 292–299.

Moore, C.P. 1976. Uso del forraje de yuca en la alimentación de rumiantes. In Memoria del Seminario Internacional de Ganadería Tropical, Acapulco, Guerrero, Mexico, 8–12 March 1978. 47–63.

Mosse, B., Powel, C. Ll., and Hayman, D.S. 1975. Plant growth responses to vesicular arbuscular mycorrhiza. IX Interactions between VA mycorrhiza, rock phosphates and symbiotic nitrogen fixation. New Phytol. 76, 331–342.

Mouttapa, F. 1973. Soil aspects in the practice of shifting cultivation in Africa and the need for a common approach to soil and land resources evaluation. Rome, Italy, Food and Agriculture Organization of the United Nations (FAO), Soils Bulletin 24, 37–47.

Murillo A., G. 1962. Estudios sobre yuca (*Manihot utilissima* Pohl) (Studies on cassava). San Jose, Costa Rica, Universidad de Costa Rica (UCR), Estación Experimental Agrícola Fabio Baudrit Moreno, 105p.

Muthukrishnan, D.R., Thamburaj, S., and Shanmuganu, A. 1973. Tapioca needs less water and care. Farm and Factory 7(9), 29–30.

Nair, G.M. 1978. Improved cultural practices of cassava. In Hrishi, N. and Gopinathan Nair, R., ed., Cassava Production Technology 21–24.

Narasimhan, V. and Arjunan, G. 1976. Effect of plant density and cultivation method on the incidence of mosaic disease of cassava. Indian J. Mycol. Plant Pathol. 189–191.

Nestel, B. 1973. Current trends in cassava research. Presented at the Third International Symposium on Tropical Root Crops held at IITA, Ibadan, Nigeria, 2–9 December 1973. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA), 17p. (Mimeo)

ed. 1976. African cassava mosaic: report of an indisciplinary workshop held at Muguga, Kenya, 19–22 February 1976. Ottawa, International Development Research Centre, IDRC-071e, 48p.

Nestel, B. and Cock, J. 1976. Cassava: the development of an international research network. Ottawa, International Development Research Centre, IDRC-059e, 70p.
Nestel, B. and MacIntyre, R., ed. 1973. Chronic cassava toxicity: proceedings of an interdisciplinary workshop held at London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 162p.
Ngongi, A.G.N. 1976. Influence of some mineral nutrients on growth, composition and yield of cassava (*Manihot esculenta* Crantz). Ithaca, New York, Cornell University. (Ph.D. thesis)
Ngongi, A.G.N., Howeler, R.H., and MacDonald, H.A. 1977. Effect of potassium and sulphur on growth, yield and composition of cassava. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 107–113.
Nijholt, J.A. 1935. Opname van voedingsstoffen uit den bodem door cassava (Absorption of nutrients from the soil by a cassava crop). Buitenzorg, Algemeen Proefstation voor den Landbouw. Korte mededeelingen No. 15.
Ninam, C.A., Abraham, S., Nair, P.N.C., and Cyriac, K.J. 1977. Effect of planting season on yield in cassava. Tropical Root and Tuber Crops Newsletter 10, 6–7.
Nitis, I.M. 1977. Stylosanthes as companion crop to cassava (*Manihot esculenta*). Denpasar, Bali, Udayana University, Faculty of Veterinary Science and Animal Husbandry. International Foundation for Science (IFS), Research Grant Agreement No. 76.
Nitis, I.M. and Suarna, M. 1977. Undergrowing cassava with stylo grown under coconut. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 98–103.
Nitis, I.M. and Sumatra, T.G.N. 1976. The effect of fertilizers on the growth and yield of cassava (*Manihot esculenta* var. Gadang) undersown with stylo (*Stylosanthes guyanensis* cv. Schofield) at Benebel, Bali. Denpasar, Bali, Universitas Udayana, Fakultas Kedokteran Heivan dan Peternakan, Bulletin No. 048.
Nopamornbordee, V., Nakavirojana, C., Roong-Ruang, S., Kitichaichananontha, P., and Kanakorn, P. 1967. Methods of nitrogen application for cassava; effect of slowly releasing nitrogen fertilizers. Thailand, Agricultural Chemistry Section, Department of Agriculture, Annual Report 1967, 1114–1119.
Normanha, E.S. 1946. Culturas subsidiárias na fazenda de café. II. A mandioca. Sao Paulo, Brasil, Boletim da Superintendencia dos Servicos do Café, 21, 189–199.
1951. Adubação da mandioca no Estadã de São Paulo. I. Efeito da adubação mineral (Cassava fertilization in the State of Sao Paulo. I. Effect of mineral fertilization). Bragantia 11(7–9), 181–194.
1960. Adubação da mandioca e mamoneiras em terras fracas (Manuring of cassava and castor oil plantations in sterile soils). Chácaras e Quintaes 10, 162.
1961. Adubação da mandioca (Fertilization of cassava). FIR 3(8), 18–19.
1970. General aspects of cassava root production in Brazil. In Tropical Root and Tuber Crops Tomorrow. Proceedings of the International Symposium on Tropical Root and Tuber Crops, 2nd, Honolulu and Kapaa, Kauai, Hawaii, 1970. Honolulu, University of Hawaii, 61–63.
1971. Yuca; observaciones y recommendaciones sobre su cultivo en Nicaragua. Managua, Banco Central de Nicaragua, 29p.
1975. Suggested guidelines for FAO's role in increasing and improving productivity of tropical root crops. Rome, Italy, Food and Agriculture Organization of the United Nations (FAO).
1976a. A mandioca no Brasil e no mundo. In Curso Intensivo Nacional de Mandioca I. Cruz das Almas, Bahía, Brasil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF), 9–21.
1976b. O plantio da mandioca. In Primeiro Curso Intensivo Nacional de Mandioca, Cruz das Almas, Bahía, Brasil. 190–197.
Normanha, E.S. and Freire, E.S. 1959. Consequencias da aplicaçao de adubos em contato com ramas de mandioca (Effect of fertilizer application in contact with cassava cuttings). Bragantia 18, 1–4.
Normanha, E.S. and Pereira, A.S. 1947. Resultados experimentais sobre épocas de plantio da mandioca. Rev. Agric. 22(4/6), 135–142.
1948. Melhores épocas de plantio para mandioca. Rev. Agric. 23, 237–248.
1950. Aspéctos agronómicos da cultura da mandioca (*Manihot utilissima* Pohl). Bragantia 10(7), 179–202.
1953. Comunicado da diretoria de publicidade agrícola. Recomendaçoẽs para o plantio da mandioca. Rev. Agric. 28, 264.
1963. Cultura da mandioca. Agronomico (Campinas), 15(9/10), 9–35.
1964. Cultura da mandioca. Campinas, São Paulo, Instituto Agronomico, Boletim No. 124, 29p.
Normanha, E.S., Pereira, A.S., and Freire, E.S. 1968. Modo e época de aplicaçao de adubos minerais em cultura de mandioca. Bragantia 27(12), 143–154.
North Carolina State University (NCSU). 1975. Annual report 1974. Raleigh, North Carolina, NCSU, Agronomic-Economic Research on Tropical Soils, Soil Science Department.
Nunes, W. de O., Britto, D.P.P. de S., Bergallo, N. de A., and Oliveira, A.B. de. 1976. Espaçamento para mandioca em solos fluminenses de baixa

fertilidade. Pesqui. Agropecu. Bras., Sér. Agron. 11, 59–64.

Nunes, W. de, O., Britto, D.P.P. de S., Menegueilli, C.A., Aruda, N.B. de, and Oliveira, A.B. de. 1974. Resposta da mandioca a adubaçao mineral e a métodos de aplicaçao do potássio em solos de baixa fertilidade (Response of cassava to mineral fertilization and methods of potassium application in low-fertility soils). Pesqui. Agropecu. Bras. Sér. Agron. 9, 1–9.

Nunes, W. de O. and Oliveira, A.B. de. 1972. Resultados preliminares de pesquisas com mandioca. In Reunião da Comissão Nacional da Mandioca, Ministerio da Agricultura, Brasil.

Nwosu, N.A. 1973. Some indigenous cropping systems of E. Nigeria. Presented at the Third International Symposium on Tropical Root Crops held at IITA, Ibadan, Nigeria, 2–9 December 1973. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA).

Nye, P.H. and Greenland, D.G. 1960. The soil under shifting cultivation. Harpendan, Com. For. Bureau of Soils, Technical Communication No. 51.

Nyira, Z.M. 1978. *Mononychellus tanajoa* Bondar. Biology, ecology and economic importance. In Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7–12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 155–159.

Obigbesan, G.O. 1977. Investigations on Nigerian root and tuber crops. Response of cassava cultivars to potassium fertilizer in western Nigeria. J. Agric. Sci. 89, 23–27.

Obigbesan, G.O. and Fayemi, A.A.A. 1976. Investigations on Nigerian root and tuber crops. Influence of nitrogen fertilization on the yield and chemical composition of two cassava cultivars (*Manihot esculenta*). J. Agric. Sci. 86, 401–406.

Odigboh, E.W. 1978. A two-row automatic cassava cuttings planter: design, development and prototype constructions. J. Agric. Eng. Res. 23, 109–116.

Ofori, C.S. 1970. Absorption and translocation of phosphate through cassava tubers (*Manihot esculenta* Crantz). Ghana J. Agric. Sci. 3, 203–205.

1973. Decline in soil fertility status of a tropical forest ochrosol under continuous cropping. Exp. Agric. 9, 15–22.

Okigbo, B.N. 1977a. Farming systems and soil erosion in West Africa. In Greenland, D.J. and Lal, R., ed., Soil Conservation and Management in the Humid Tropics. U.K., John Wiley and Sons Ltd.

1977b. International Institute of Tropical Agriculture (IITA), preliminary cassava inter-planting trials. Presented at the First NAFPP National Cassava Workshop, Umudike, Nigeria.

1978. Cropping systems and related research in Africa. Addis Ababa, Ethiopia, Association for the Advancement of Agricultural Sciences in Africa (AAASA), Publication Series OT-1, 81p.

1979a. Effects of methods of seedbed preparation and mulching on cassava yield. In Lal, R., ed., Soil Tillage and Crop Production. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA), Series 2, 75–92.

1979b. Effects of preplanting cultivation and mulching on the yield and performance of Cassava (*M. esculenta* Crantz). In Lal, R. and Greenland, D.J., ed., Soil Physical Properties and Crop Production in the Tropics. U.K., John Wiley and Sons Ltd. (In press)

Okigbo, B.N. and Lal, R. 1977. Role of cover crops in soil and water conservation. In Soil Conservation and Management in Developing Countries. Rome, Italy, Food and Agriculture Organization of the United Nations (FAO), Soil Bulletin 33, 97–108.

Oliveros, B., Lozano, J.C., and Booth, R.H. 1974. A phytophthora root rot of cassava in Colombia. Plant Dis. Rep. 58, 703-705.

Onochie, B.E. 1975. Critical periods for weed control in cassava in Nigeria. PANS (Pest Artic. News Summ.), 21(1), 54–57.

Onochie, B.E., Makanjuola, G.A., and Schulte, E.E. 1973. A study to determine the suitability of present casssava varieties to mechanical harvesting. Presented at the Third International Symposium on Tropical Root Crops held at IITA, Ibadan, Nigeria, 2–9 December 1973. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA). (Mimeo)

Onwueme, I.C. 1978a. Evaluation of the performance of cassava when grown from inverted stem cuttings. J. Agric. Sci. 90, 149–156.

1978b. The tropical tuber crops. U.K., John Wiley and Sons Ltd., 234p.

Peixoto. A.R. 1963. Mandioca. Rio de Janeiro, Brasil, Ministério da Agricultura, Serviço de Informação Agrícola. Produtos Rurais No. 5, 15p.

Pereira, A.S. 1971. Contribuição do Instituto Agronômico ao I° Encontro de Engenheiros Agronômos pesquisadores em mandioca dos paises andinos e do Estada de São Paulo. Agronomico (Campinas), 23, 21–33.

Phillips, J.M. and Hayman, D.S. 1970. Improved procedures for cleaning roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans. Br. Mycol. Soc. 55, 158–161.

Phillips, T.P. 1974. Cassava utilization and potential markets. Ottawa, International Development Research Centre, IDRC-020e, 182p.

Pierson, C.L. 1973. Agronomic aspects of soil conservation. Presented at the FAO/SIDA Regional Seminar on Shifting Cultivation and Soil Conservation in Africa. Rome, Italy, Food and Agriculture Organization of the Untied Nations (FAO), Stockholm, Sweden, Swedish International Development Authority (SIDA), 8p. (Mimeo)

Pires de Mattos, P.L., Da Silva S., L., Correa C., R., and Carvalho M.P., M. 1979. Adaptação de espaçamentos em fileiras duplas para a cultura da mandioca (*Manihot esculenta* Crantz). In Resumos 1° Congresso Brasileiro de Mandioca, de 25 a 30 de Novembro-1979, Bahía, Brasil. 17p.

Potty, V.P. 1978. Occurrence of vesicular arbuscular mycorrhiza in certain tuber crops. J. Root Crops 4, 49–50.

Prévot, P. and Ollagnier, N. 1958. La fumure potassique dans les régions tropicales et subtropicales (K fertilization in tropical and subtropical regions). In Potassium Symposium, Berne. 277–318.

Ramirez, A. 1978. Fertilización de la yuca (*Manihot esculenta* Crantz) (Fertilization of cassava). In Programa Nacional de Suelos, Informe de Progreso ICA. Bogotá, Colombia, Instituto Colombiano Agropecuario (ICA), 104–108.

Rao, N.S. 1952. A short note on tapioca. Mysore Agric. J. 27(3), 70–73.

Redhead, J.F. 1979. Soil mycorrhiza in relation to soil fertility and productivity. In Mongi, H.O., Huxley, P.A., and Spurgeon, D., ed., Soils Research in Agroforestry. Nairobi, Kenya, Proc. Expert Consultation, 26–30 March 1979.

Ribeiro Filho, J. 1946. Cultura e utilização da mandioca. Rev. Ceres 7(38), 88–100.

1966. Cultura da mandioca. Viçosa, Brasil, Universidade Rural do Estado de Minas Gerais, Escola Superior de Agricultura, 80p.

Rio Grande do Norte. Secretaria da agricultura. Pesquisa a experimentação com culturas alimentares: mandioca, anos 1971–1975.

Roche, L. 1973. The practice of agri-silviculture in the tropics with special reference to Nigeria. Presented at the FAO/SIDA Regional Seminar on Shifting Cultivation and Soil Conservation in Africa. Rome, Italy, Food and Agriculture Organization of the United Nations (FAO), Stockholm, Sweden, Swedish International Development Authority (SIDA), 29p. (Mimeo)

Roche, P., Velly, J., and Joliet, B. 1957. Essai de détermination des seuils de carence en potasse dans le sol et dans les plantes (Determination of the critical level of potassium deficiency in soil and plants). Rev. Potasse.

Rodriguez, J.M. 1975. Fertilización de la yuca (Fertilization of cassava). In Curso Sobre Producción de Yuca. Medellin, Colombia, Instituto Colombiano Agropecuario (ICA), Regional No. 4.

Rodriguez, N.F. and Sanchez de B., C.A. 1963. Importancia del tipo de estaca para la producción de mandioca en Misiones. Rev. Invest. Agric. 17(3), 289–302.

Rodriguez, N.F., Sanchez de B., C.A., and Tarabanoff, J. 1966. Algunos factores que influyen en el comportamiento del cultivo de mandioca en la provincia de Misiones. Rev. Invest. Agropecu. 3(11), 167–208.

Rogers, D.J. and Appan, S.G. 1972. Cassava (*M. esculenta* Crantz), the plant, world food production and its importance in world food supply. In Hendershott, C.R., et al., ed., A Literature Review and Research Recommendations on Cassava. Athens, Georgia, University of Georgia, 1–14.

Rosas, S.C. 1969. Influencia de la modalidad de siembra y tamaño de la estaca de yuca. La Molina, Perú, Universidad Nacional Agraria, Programa, 7p.

Rovira, A.D. 1976. Studies on soil fumigation. I Effects on amonium. nitrate, and phosphate in soil and on growth, nutrition and yield of wheat. Soil Biol. Biochem. 8, 241–247.

Sampaio, C.V. and Conceição, A.J. da. 1972. Competição de espaçamento (*Salangorzinha*). In Relatorio Semestral de Andamento e Avaliação de Pesquisas. Cruz das Almas, Bahía, Brasil, Universidade Federal da Bahía, Escola de Agronomía/BRASCAN Nordeste, Jul/Dez.

1975. Espaçamento na cultura da mandioca (*Manihot esculenta* Crantz) In Projeto Mandioca. Cruz das Almas, Bahiá, Brasil, Universidade Federal da Bahía, Escola de Agronomiá/BRASCAN Nordeste, 99–106.

Samuels, G. 1970. The influence of fertilizer levels and sources on cassava production on a Lares Clay in Puerto Rico. In Proceedings of the Seventh Annual Meeting of the CFCS, Martinique, Guadaloupe.

Sanchez de B., C.A. and Rodriguez, N.F. 1967. Conservación invernal de tallos de mandioca destinados a estaca-semilla en la provincia de Misiones (Argentina). Rev. Investi. Agropecu. Sér. 2, 4(17), 331–349.

Sanders, F.E. 1975. The effect of foliar-applied phosphate on the mycorrhizal infections of onion roots. In Sanders, F.E., Mosse, B., and Tinker, P.B., ed., Endomycorrhizas. Proceedings of a Symposium held at the University of Leeds, 22–25 July 1974. London, Academic Press.

Santana, A.M., Carvalho, J.E.B. de, and Borges, I.O. 1975. Competiçao de fontes de nitrogenio em solos para mandioca (Effects of different sources of nitrogen on cassava production). In Cruz das Almas, Bahía, Brasil, Universidade Federal da Bahía, Escola de Agronomiá/BRASCAN Nordeste, Serie Pesquisa 1(1), 39–55.

1979. Tres niveis de adubaçao NPK na cultura da mandioca (*Manihot esculenta* Crantz) (Three levels of NPK fertilization in cassava). Salvador Bahía, Brasil, Congreso Brasileiro de Mandioca, 23–30 November.

Santos, E.O., Bessa, M., and Lima, P.B. de. 1972. Mandioca; recomendaçoes tecnológicas. Brasil, Departamento Nacional de Pesquisa Agropecuária, Instituto de Pesquisas e Experimentação Agropecuária do Nordeste (IPEANE), Circular No. 18, 11p.

Santos, G.A.L. dos, Grassi, N., Cruz, L.S.P., and Hertwig, K.V. 1973. Controle químico de ervas daninhas na cultura da mandioca (*Manihot esculenta* Crantz). Biológico 39(8), 195–198.

Santos, R.B. 1967. Yield of cassava under different methods of land preparation. Agric. Indust. Life 29(7), 22–26.

Saraswat, V.N. and Chattiar, T.S. 1976. Effect of organic and inorganic sources of nitrogen on cassava (*Manihot utilissima* L). Indian Agric. 20(1), 23–26.

Sasidhar, V.K. and Sadanandan, N. 1976. Tapioca after cowpea gives higher yield. Indian Farming 26(6), 23.

Scaife, A. 1968. Cassava cultivation in western

Tanzania. Tanzania, Ukirigular Progress Report 3, 1–2.

Schmitt, J. 1955. Cultivo abundante y explotación industrial de la yuca (Cassava cultivation and industialization). Suelo Tico 8, 152–158.

Schulte, E.D., Makanjuola, G.A., and Onochie, B.E. 1973. Mechanization of cassava production and planting. Presented at the Third International Symposium on Tropical Root Crops held at IITA, Ibadan, Nigeria, 2–9 December 1973. Ibadan, Nigeria, International Institute of Tropical Agriculture (IITA). (Mimeo)

Seixas, B.L.S. 1976. Preparo do solo. In Primeiro Curso Intensivo Nacional de Mandioca. Cruz das Almas, Bahía, Brasil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro Nacional de Pesquisa Mandioca e Fruticultura (CNPMF), 183–199.

Sena, Z.F. da and Campos, H. dos R. 1973. Estudo do sistema radicular da mandioca, *Manihot esculenta* Crantz, submetida a diferentes frequencias de irrigaçao (Study of the root system of cassava, *Manihot esculenta* Crantz, under frequency period of irrigation). Cruz das Almas, Bahía, Brasil, Universidade Federal da Bahía, Escola de Agronomia.

Shanholtz, V.O. and Lillard, J.H. 1969. Tillage system effects on water use efficiency. J. Soil Water Conserv. 24(5) 186–189.

Shanmugavelu, K.G., Thamburaj, S.A. Shanmugham, A., and Gopalaswamy, N. 1973. Effect of time of planting and irrigation frequencies on the yield of tapioca. Indian J. Agric. Sci. 43(8), 789–791.

Shanmugham, A. and Srinivasan, C. 1973. Influence of number of shoots per plant on the growth and yield of cassava. Calcutta Farm J. 14(7), 19–22.

Silva, A.A. da, Silva, J.F. da, O Begazo, J.C.E., and Condé, A.R. 1979. Controle químico de plantas daninhas na cultura da mandioca (*Manihot esculenta* Crantz). Cariacica, Empresa Capixaba de Pesquisa Agropecuária (EMCAPA), Boletim Técnico No. 01, 26p.

Silva, J.R. da. 1965. Efeito de certos adubos quimicos sobre o stand da mandioca (Effect of chemical fertilizers on cassava stand). Cienc. Cult. (São Paulo), 17, 193–194.

1970. O programa de investigaçao sobre mandioca no Brasil. In Primeiro Encontro de Engenheiros Agronomas Pesquisadores en Mandioca dos Paises Andinos e do Estado de São Paulo. Campinas, Brasil, Instituto Agronomico do Estado de São Paulo, 61–72.

1971a. O programa de investigações sobre mandioca no Brasil. Agronomico (Campinas), 23, 33–48.

1971b. O programa de mandioca no Instituto Agronomico do Estado de São Paulo. Agronomico (Campinas), 23, 49–71.

1979. Some aspects of cassava production in Brazil. Presented at a Workshop on Pre-Release Testing of Agricultural Technology held at CIAT, Cali, Colombia, 25p.

Silva, J.R. da and Freire, E.S. 1968. Efeito de doses crescentes de nitrogenio, fosforo e potassio sobre a produçao de mandioca em solos de baixa e alta fertilidade (Response of cassava to increasing doses of N, P, and K). Bragantia 27, 357–364.

Silva, J.R. da, Lorenzi, J.O., Monteiro, da, Normanha, E.S., and Campos, H. de. 1979. Efeito do calcário e de micronutrientes na cultura da mandioca (*Manihot esculenta* Crantz). São Paulo, Instituto Agronomico de Campinas, 9p.

Silva, J.R. da, Lorenzi, J.O., Monteiro, da, Normanha, E.S., and Pereira, A.S. 1979. Experimentos de algumas fontes de fósforo para mandioca. São Paulo, Instituto Agronomico de Campinas, 8p.

Silva, L.G. 1970. Adubação NPK na cultura da mandioca em tabuleiro costeiro no Estado da Paraíba. Pesq. Agrop. Nord. 2(1), 73–75.

Silva, L.G., Souza, J.B. de., Silva, J.C. da., and Lucas, A. de P. 1969. Acão de macronutrientes e manganês na cultura da mandioca em solos de tabuleiros costeiros do nordeste. Recife, Superintendencia do Desenvolvimento do Nordeste (SUDENE), 29p.

Siqueira, L.A. 1973. Mandioca: resultados experimentais. Cruz das Almas, Bahía, Brasil, Instituto de Pesquisas e Experimentação Agropecuária do Leste (IPEAL), Circular No. 36, 34p.

Sittibusaya, C. and Kurmarohita, K. 1978. Soil fertility and fertilization. In Proceedings of a Workshop on Cassava Production and Utilization, May 10–12 1978. Bangkok, Thailand, Asian and Pacific Council (ASPAC).

Sittibusaya, C., Utayapat, P., and Nakavirojana, C. 1974. A study on the method of fertilizer application for cassava. In Progress Report on Soils and Fertilizer Studies of Field Crops for 1974. Thailand, Department of Agriculture, Ministry of Agriculture.

Smith, L.R. 1968. Informe de los ensayos sobre la producción de yuca en el Cibao. Santiago de los Caballeros, República Dominicana, Instituto Superior de Agricultura.

Sobral, L.F., Barreto, A.C., Siqueira, L.A., Santos, Z.G. dos., Souza, R.F., Rezende, J. de O., and Ribeiro, J.V. 1976. Efeitos da macro e micronutrientes na produção da mandioca (*Manihot esculenta* Crantz). Sergipe, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Comunicado Técnico No. 1, 13p.

Soria, V.J., et al. 1975. Investigación sobre sistemas de producción agrícola para el pequeño agricultor del trópico. Turrialba 25(3), 283–293.

Spear, S.N., Asher, C.J., and Edwards, D.G. 1978. Response of cassava sunflower, and maize to potassium concentration in solution. II. Potassium absorption and its relation to growth. Field Crops Res. 1, 363–373.

Spear, S.N., Edwards, D.G., and Asher, C.J. 1978a. Effects of nutrient supply on critical nutrient concentrations in cassava plants. Eighth Intern. Col. Plant Analyses and Fertilizer Problems, Auckland, New Zealand, 28 August to 1 September 1978.

1978b. Response of cassava, sunflower, and maize to potassium concentration in solution. III. Interactions between potassium, calcium, and magnesium. Field Crops Res. 1, 375–389.

Stephens, D. 1960. Fertilizer trials on peasant farms in Ghana. Empire J. Exp. Agric. 109, 1–22.
Stephens, J.M. 1965. Growing cassava in Florida. Gainsville, EUA, University of Florida, Agricultural Extension Service, Extension Vegetable Crops, Report 65-1, 3p. (Mimeo)
Tafur, N.A. 1976. Efecto de varios sistemas de produccíon agrícola sobre la resistencia mecánica de los suelos. Turrialba, Costa Rica, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), 311p. (Thesis)
Takyi, S.K. 1972. Effects of potassium, lime and spacing on yields of cassava (*Manihot esculenta* Crantz). Ghana J. Agric. Sci. 5, 39–42.
1974. Effects of nitrogen, planting method and seedbed type on yield of cassava (*Manihot esculenta* Crantz). Ghana J. Agric. Sci. 7, 69–73.
Tan, K.H. and Bertrand, A.R. 1972. Cultivation and fertilization of cassava. In Hendershott, C.H., et al., ed., A Literature Review and Research Recommendations on Cassava. Athens, Georgia, University of Georgia, 37–72.
Tanaka, R.T., Correa, R., Rocha, B.V. da, Guedes, G.A.A., and Andrade, A.M.S. 1979. Estudo sobre a aplicação de diferentes níveis de fósforo, potássio e calagem na produção da Mandioca (*Manihot esculenta* Crantz) num solo sobre vegetação de cerrado. Belo Horizonte, Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), 9p.
Tarazona, C., Marin, G., and Leon, A. 1973. Respuesta de la yuca (*Manihot esculenta* Crantz) a la fertilización en parcelas demostrativas (Response of cassava to fertilization in demonstration plots). Bogotá, Colombia, Instituto Colombiano Agropecuario (ICA).
Tardieu, M. and Fauche, J. 1961. Contribution à l'étude des techniques culturales chez le manioc. Agron. Trop. 16(4), 375–386.
Ternes, M. and Ishy, T. 1978. Herbicidas em mandioca. Florianópolis, Empresa Catarinense de Pesquisa Agropecuária (EMPASC), Comunicado Técnico No. 11, 2p.
Tineo, J. 1976. Selección de estacas y la siembra de yuca. Agro Información 1(8), 29–31.
Tobon, C., J.H., Turrent, F.A., and Martinez, G.A. 1975. Comportamiento de algunos sistemas agrícolas tradicionales a varias prácticas de producción en el oriente Antioqueño, Colombia. Agrociencia 19, 45–67.
Toro, J.C. 1979. Three years of cassava technology evaluation in Colombia. Field Crops Res. 2.
Toro, J.C., Castro, A., and Celis, E. 1976. Selección y preparación de material para siembra de yuca. In Curso Sobre Producción de Yuca. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 197–204.
1978. Planting methods and care at early growth stage of cassava. In Dominguez, C., ed., Cassava Production Course. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), 108–114.
Toro, J.C. and Jaramillo, G. 1974. Metodos de colheita da mandioca. In Curso Especial de Aperfeiçoamento para Pesquisadores de Mandioca. CIAT, Cali, Colombia, 3–31 August 1974, 382–392.
Tourte, R. and Moomaw, J.C. 1977. Traditional African systems of agriculture and their improvement. In Leakey, C.L.A. and Wills, J.B., ed., Food Crops of the Lowland Tropics. U.K., Oxford University Press.
Tribuzi, H.S. 1963. Trabalho completo sôbre e cultura da mandioca. Sítios e Fazendas 29(12), 22–24.
Umanah, E.E. 1977. Cassava research in Nigeria before 1972. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the Fourth Symposium of the International Society for Tropical Root Crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 137–141.
Valles, C.R.P. 1977. Periodo crítico de competencia de malezas en yuca en Tarapoto, CRIA. III Convenio DGI-CIAT, Campaña 1976–1977, 5p.
Vargas, O.H. 1978. The white scale (*Aonidomytilus albus* Ckll.) on cassava. In Brekelbaum, T., Bellotti, A., and Lozano, J.C., ed., Proceedings of the Cassava Protection Workshop held at CIAT, Cali, Colombia, 7–12 November 1977. Cali, Colombia, Centro Internacional de Agricultura Tropical (CIAT), Series CE-14, 199–202.
Viegas, A.P. 1976. Estudos sobre a mandioca. São Paulo, Brasil, Instituto Agronômico do Estada de São Paulo/BRASCAN Nordeste, 214p.
Vieweg, B. and Wims, W. 1973. Problems with the change from shifting to permanent cultivation on a light soil in the Kilombero Valley, Tanzania. Presented at the FAO/SIDA Regional Seminar on Shifting Cultivation and Soil Conservation in Africa. Rome, Italy, Food and Agriculture Organization of the United Nations (FAO), Stockholm, Sweden, Swedish International Development Authority (SIDA), 3p. (Mimeo)
Vijayan, M.R. and Aiyer, R.S. 1969. Effect of nitrogen and phosphorus on the yield and quality of cassava. Agric. Res. J. Kerala 7, 84–90.
Villanueva, M.R. 1978. Current status of cassava in the Philippines. Submitted to the Workshop on Cassava Production and Utilization, 9–14 May 1978, Khonkaen, Thailand.
Wahab, A.H., Robinson, P.F., and Hassan, I. 1977. Mechanized planting of cassava stem cuttings on Guyana's light peats and peaty clays. Turrialba 27(2), 137-141.
Yost, R.S. and Fox, R.L. 1979. Contribution of mycorrhiza to the P nutrition of crops growing on an Oxisol. Field Crops Res. (In press)
Zaag, P. Van Der, Fox, R.L., Pena, R.S., and Yost, R.S. 1979. Phosphorus nutrition of cassava including mycorrhizal effects on P, K, S, Zn and Ca uptake, Field Crops Res. (In press)
Zijl, C.E. Van Der. 1930. Verbetering der cassave cultuur door middel van proefvelden. Wageningen, Netherlands H. Veenman and Zonen, 127p.

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE • CENTRE DE RECHERCHES POUR LE DÉVELOPPEMENT INTERNATIONAL

CANADA